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Editors of the Cyclopædia of Practical Medicine.

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THE FOLLOWING ARE THE

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1. D'Amador and Saucerotte on the influence of Pathological Anatomy upon Medicine. 2. Lonsdale and Burke on Fractures: Treatment by the "Immoveable Apparatus." 3. Höegh-Guldberg and Cross on Delirium Tremens. 4. Madden on Cutaneous Absorption. 5. Chase, Finck, Belmas, Bonnet, and Gerdy, on the Radical Cure of Hernia. 6. Chomel and Bouillaud on the Nature and Treatment of Rheumatism. 7. The Transactions of the Provincial Medical and Surgical Association. Vol. VI. 8. Ehrenburg, Berres, Treviranus, Remak, Valentin, Emmert, Burdach, and Müller, on the Structure of the Brain and Nerves. 9. Dendy and Dick on the Cutaneous Diseases of Children. 10. Le Canu and Denis on the Chemistry of the Blood in Health and Disease. 11. Alcock's Medical History and Statistics of the British Legion of Spain. 12. Cormack, Bouillaud, Amussat, Velpeau, on the Introduction of Air into the Veins. 13. The Life of Dr. Jenner; by Dr. Baron. 14. Granville on Counter Irritation. 15. Mitscherlich's Practical and Experimental Chemistry; translated by Dr. Hammick. 16. Royle's Essay on the Antiquity of Hindoo Medicine. 17. Coulson on Diseases of the Bladder. 18. Macreight's Manual of British Botany. 19. Hutchinson's Narrative of a Recovery from Tic Douloureux. 20. Prichard's Practical Observations on Hysteria. 21. Gurlt's Elements of the Comparative Physiology of the Domestic Mammalia. 22. Wetzlar on the injurious Consequences of unnecessary and immoderate Bloodletting. 23. Ure's Practical Compendium of the Materia Medica.

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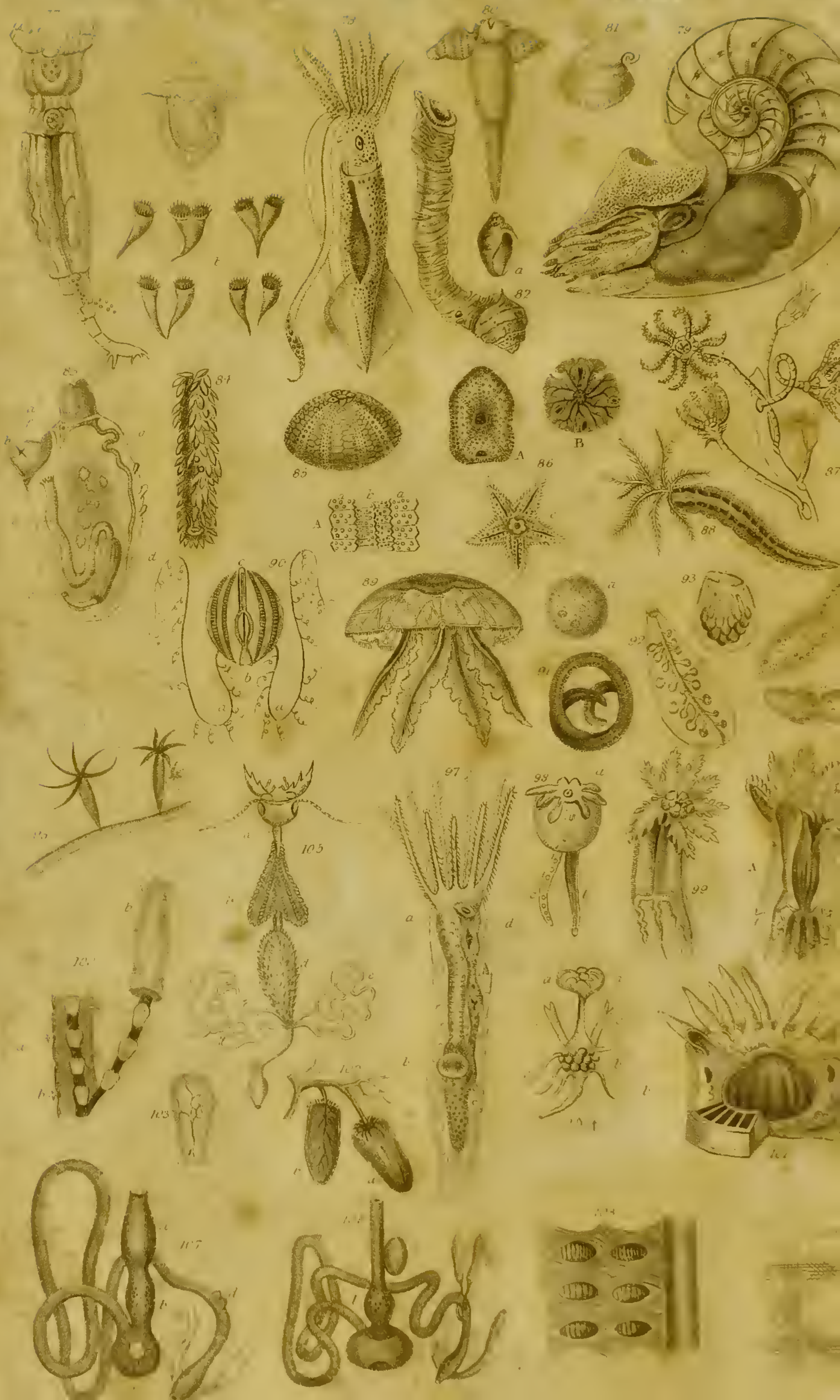
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PRINCIPLES

OF

GENERAL AND COMPARATIVE PHYSIOLOGY,

INTENDED AS AN

INTRODUCTION TO THE STUDY OF HUMAN PHYSIOLOGY,

AND AS A

GUIDE TO THE PHILOSOPHICAL PURSUIT OF NATURAL HISTORY.

BY

WILLIAM B. CARPENTER,

MEMBER OF THE ROYAL COLLEGE OF SURGEONS, LONDON;
LATE PRESIDENT OF THE ROYAL MEDICAL AND ROYAL PHYSICAL SOCIETIES,
AND FELLOW OF THE ROYAL BOTANICAL SOCIETY, EDINBURGH;
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TO

SIR JOHN F. W. HERSCHEL, BART.,

K.H. F.R.S. L. AND E. ETC.,

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MOST RESPECTFULLY DEDICATED,

AS A TRIBUTE DUE ALIKE

TO

HIS HIGH SCIENTIFIC ATTAINMENTS,

AND MORAL WORTH,

AND AS AN EXPRESSION OF GRATITUDE FOR

THE BENEFIT DERIVED FROM HIS

"DISCOURSE ON THE STUDY OF NATURAL PHILOSOPHY,"

BY

THE AUTHOR.

PREFACE.

However trite may be the reason so commonly assigned by writers on any subject for presenting themselves to the public, the Author is not disposed to omit its mention as regards himself. During the course of his Physiological studies, he has felt, in common with many others, the want of a Treatise which should give a comprehensive view of the Science, embracing whatever general principles may be regarded as firmly established, and illustrating them as fully as could be done within moderate limits, yet without distracting the attention by profuseness of detail. He has long, therefore, kept in view the production of such a work as the present, should it not be anticipated by some other on the same plan; and in now deciding upon its publication, he has been influenced by the opinions of individuals of high eminence as Teachers of Physiology, as well as by the encouragement he has received from some who take an elevated station in Physical Science, and who have experienced the same deficiency.

It is now generally acknowledged that Physiology can only be properly studied by a constant reference to the comparative structure and functions of many different classes of Animals; and in most of the recent works on this Science, an outline of the development and actions of each system in the inferior tribes is prefixed to the details relating to its condition in man. This outline is filled up in the present volume, not only by amplifying the portion of it which relates to the Animal Kingdom, but also by the introduction of a similar view of the comparative structure and functions of Vegetables, which is here shown to be governed by the same laws. It is this which constitutes the peculiar feature of the work; as the author believes it to be the first attempt, in this country at least, to form anything like a

systematic Comparative Physiology of Vegetables. The translation of the elaborate Comparative Physiology of Tiedemann would, indeed, have occupied this ground; but it is still incomplete, and is likely to remain so; and the mass of details which it embraces, unconnected by comprehensive principles, renders it most tedious and embarrassing to the student. From that most valuable storehouse of *facts*, the present volume differs essentially, therefore, in plan; this being devoted to the explanation and illustration of general *laws*.

Although his work is especially intended as an Introduction to the study of Human Physiology for the use of the Medical Student, the author has kept in view the wants of the General Reader, to whom he hopes to make intelligible some of the highest doctrines in this most interesting science. For this purpose he has given explanations of most of the scientific terms employed, in the situations where they could be most appropriately introduced; and reference to them is facilitated by the copiousness of the Index, which thus serves the purpose of a Glossary. He has also expressed himself in general terms in some instances where more detail might otherwise have been admitted; but he trusts that he has, by this means, avoided all chance of offending the true delicacy even of the female reader.

The desire which he has felt to moderate the extent of the volume, and to make it generally acceptable both in size and price, has compelled the author unwillingly to omit the greater number of references which he had designed to introduce, and which his own experience leads him to consider as of importance in a work like the present. He has, however, retained those which concern insulated Memoirs on particular subjects, or facts of novel and peculiar interest; and the following list comprises the Systematic Treatises on the authority of which he has usually relied.

Alison's Outlines of Physiology .... Edinb. 1836
Bostock's Elementary System of Physiology .... London 1836
Burdach.—Traité de Physiologie, traduit par Jourdain ...... Paris 1837-8
Burmeister.—Manual of Entomology, translated by Shuckhard London 1836
Burnett's Outlines of Botany .... London 1835
Carus.—Traité Elémentaire d'Anatomie Comparée, traduit par Jourdain.. Paris 1835
Decandolle.—Organographie Végétale .... Paris 1827
———— Physiologie Végétale .... Paris 1832
Edwards on the Influence of Physical Agents on Life, translated by Drs. Hodgkin and Fisher .... London 1832
Elliotson's Physiology .... London 1835-8

Fletcher's Rudiments of Physiology .... Edinb. 1837
Grant's Outlines of Comparative Anatomy .... London 1835-8
——— Lectures published in the Lancet—Vols. XXV, XXVI.
Graves's Introductory Lectures on the Institutes of Medicine, published in the London Medical and Surgical Journal, Vol. VII.
Henslow's Descriptive and Physiological Botany .... London 1836
Kirby on the History, Habits, and Instincts of Animals (Bridgwater Treatise) .... London 1835
Lindley's Introduction to Botany .... London 1835
——— Introduction to the Natural System of Botany .... London 1837
Mayo's Outlines of Physiology .... London 1837
Müller's Elements of Physiology, translated by Dr. Baly .... London 1838
Prout on Chemistry, Meteorology, and the Function of Digestion (Bridgwater Treatise) .... London 1834
Roget's Animal and Vegetable Physiology (Bridgwater Treat.) London 1834
Smith's Philosophy of Health .... London 1835-7
Solly on the Brain and Nervous System .... London 1836
Tiedemann's Comparative Physiology, translated by Drs. Gully and Lane .... London 1834
Cyclopædia of Anatomy and Physiology
Penny Cyclopædia
Reports of the British Scientific Association

The following, amongst others, have been occasionally consulted:—

Adelon.—Physiologie de l'Homme .... Paris 1829
Blainville.—Cours de Physiologie .... Paris 1833
Buckland's Geology and Mineralogy (Bridgwater Treatise) .. London 1836
Cuvier.—Leçons d'Anatomie Comparée .... Paris 1835-8
Dutrochet.—Memaires Anatomique et Physiologiques ...... Paris 1837
Lord's Popular Physiology .... London 1834
Lyell's Principles of Geology .... London 1835
Magendie.—Leçons sur les Phénomènes Physiques de la Vie Paris 1835-8
Meckel.—Traité Général d'Anatomie Comparée, traduit par Jourdain .... Paris 1828-38
Milne-Edwards.—Elémens de Zoologie .... Paris 1834
Prichard's Researches into the Physical History of Mankind.. London 1836
Raspail.—Nouveau Système de Chimie Organique.......... Paris 1833
Serres.—Anatomie Comparée du Cerveau .... Paris 1827
Sprengel's introduction to the study of the Cryptogamia .... London 1807
Whewell's History of the Inductive Sciences .... London 1837

In the following pages is embraced the substance of an Essay on the "Laws regulating Vital and Physical Phenomena," to which was adjudged the annual Students' Prize awarded by the Medical Faculty of the University of Edinburgh for 1837; and also of an Essay on some departments of Vegetable Physiology which received the First Prize given by the Professor of Botany in the year 1836. The author has freely availed himself, also, of the liberal permission of the Editors of the British and

Foreign Medical Review to make what use he deemed proper of his contributions to that journal; especially in regard to two Papers,—one on the Study of Physiology as an Inductive Science, and the other on the Functions of the Nervous System,—which have been recently honoured with a place in its pages.

It would be ungrateful on the part of the author, were he not also to acknowledge his peculiar obligations to some, by whose instructions and personal guidance he has been greatly aided in his Physiological studies, and to whom whatever merit this production may possess is in a great measure due. To Dr. Riley, his former instructor and present colleague in the Bristol Medical School,—to Professors Grant and Lindley, of London University College,—and to Professor Alison, of the University of Edinburgh, he gladly takes this opportunity of tendering his respectful thanks; and he cannot refrain from here offering the tribute of regard to his highly-valued friend Dr. John Reid, Lecturer on Physiology in the Argyle-Square Medical School, Edinburgh, to whose clearness of thought, experimental skill, and comprehensive knowledge of his Science, he feels himself in many respects deeply indebted.

Whatever claims to originality the present Treatise may possess, the author is not disposed to put them forwards here. He has not hesitated to employ the language of other writers in the description of facts, wherever it seemed appropriate; deeming it useless to alter, for the mere sake of rendering it his own, that which may be regarded as common property. But he believes that he has never employed the *ipsissima verba* of others in the expression of opinions, without acknowledgment. The *facts* for which he holds himself responsible may, in general, be readily distinguished. The degree of novelty which any of the *inferences* from them may possess, he is content to leave it to his readers to estimate; and he will only now express the hope that, as they have not been formed hastily or inconsiderately, they may not be too readily pronounced crude or unphilosophical.

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The object of this Section, taken in connection with Chapter I. (Book I), is to show the relations between Life, or Vital Action, and Organised Structure. The argument may be thus briefly stated.—The *properties* of any aggregation of Matter depend upon the mode in which its ultimate molecules are combined and arranged, and have not an existence separate from the matter itself (150). The simplicity of our notion of the properties of inorganic matter depends upon the facility with which we may become acquainted with them, through the command which we possess over the agencies by whose operation they are manifested; and their *evident uniformity* of action enables us at once to refer them to definite and comprehensive laws (4,141). These *Laws* simply express the *conditions of action* of the material bodies which they concern (147, 148). All Physical Phenomena result from the excitement of the *physical properties* of matter by external agents; and, when these are not in operation, no change takes place (1, 9, 10, 144). In like manner, Vital Actions result from the excitement of the *vital properties* of certain forms of matter by external agents or *stimuli;* and are not manifested, or called into play, without the influence of these (10, 144, 155). These Vital properties exist only in *organised* tissues, and stand in the same relation to them as do the Physical properties to matter in general (140). They may be regarded as essentially dependent on the peculiar state in which the component particles exist. This state can only be induced by an action of *Organisation* effected upon inorganic matter by a pre-existing structure; and the change thus operated developes properties that previously lay dormant, the material particles not being, until then, in the condition required to exhibit them (10, 151, 152). In proportion as the properties thus called into exercise differ from those common to matter in general, does the organised tissue which possesses them, exhibit peculiarities of structure and composition unlike those presented by other forms of matter (11, 19, 159). These peculiarities are such that spontaneous decomposition of the elements has a constant tendency to take place, especially in the most highly organised structures; but this is kept in check, in the living body, by the continual renovation which is characteristic of Vital Action (18, 214). So long as this takes place, the vital properties are retained; but if any considerable alteration of structure or composition occur, they are perverted or altogether destroyed (152—4). All Vital Action, therefore, is dependent on two conditions;—an organised structure possessed of properties not manifested by inorganic matter; and a stimulus by which these properties are excited to action. But many of the changes concerned in the maintenance of Life are of a strictly physical character; and it is by these that the connection is effected between the Organism and the external world (159—165).

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INTRODUCTION.

ON ORGANISED STRUCTURES.

I.—*Preliminary Remarks.*

1. The most careless observer cannot fail to recognise in the world around him, many evident distinctions between living beings and inanimate objects. Perhaps the most apparent and positive of these distinctions is rather based upon a comparison of their mode of existence, than upon an examination of their intimate structure. The ceaseless tendency to change manifested in the life of the former, stands in yet more obvious contrast with the unaltering stability of the latter, than does that peculiar arrangement of elementary particles which is called Organisation, with the regular aggregation of the ultimate atoms which the Inorganic world presents. The snow-capped mountain rears its summit to the clouds, unaffected by the lapse of the ages which have rolled by since its first elevation—a monument of Nature's power; and the giant edifices erected by the hand of man on the plains of Egypt, bear to remote posterity the attestation of the former grandeur of a nation now sunk into poverty and insignificance. And what, compared with the permanence of these, is the duration of any structure subject to the conditions of vitality? To be born—to grow—to arrive at maturity—to decline—to die—to decay, is the sum of the history of every being that lives; from man in the pomp of royalty or the pride of philosophy, to the gay and thoughtless insect that glitters for a few hours in the sunbeam and is seen no more; from the stately oak, the monarch of the forest through successive centuries, to the humble fungus which shoots forth and withers in a day. How simply, yet how expressively, are these changes described in the words of the sacred writer, "Our life is as a vapour, which appeareth for a little time and then vanisheth away."

2. And yet, amidst the constant change and succession of individuals, we observe the form and character first impressed upon each race by the

Creator of all, uninterruptedly transmitted from parent to offspring through periods of indefinite duration. " One generation passeth away" —but " another cometh"—like it in structure, functions, habits, food, instincts, passions, and the limit of its existence. The mistletoe flourishes on the oak of our own forests, just as when made an object of superstitious veneration in the hallowed groves of our Druidical ancestors. The bee builds her comb with the same unvarying regularity, and stores it with the same materials now, as when her beautiful works attracted the notice of the poets and philosophers of classic ages. And man, however modified by education, however various his degree of civilisation, however elevated his condition of mental and moral refinement, is yet born the same helpless dependent being, with the same dormant faculties of body and mind, as the first offspring of our original parents.

3. In the ever-varying conditions of the animated world, then, a very superficial glance will display to us a certain degree of regularity and arrangement; and the more attentively we investigate the relations which its changes present, the more stable and definite is the assurance we obtain, that they are all harmonised and controlled by fixed *laws*, which are but simplified expressions of those conditions of action which the Creator has imposed upon organised no less than upon inorganic matter. To arrive at the knowledge of these laws, and, having attained them, to trace their application to all the countless variety of phenomena presented by the myriads of living beings whose beautiful forms people this globe, is the object of the science of Physiology,—using that term in its most extended sense, to which the designation BIOLOGY is perhaps rather applicable. That the most advantageous plan of studying it is that inductive method which has been successful in other sciences, will not perhaps now be disputed: yet the prevalence of a contrary system has long retarded its progress; and it is only within a recent period that the ends to be attained have been generally understood, and the most satisfactory means of pursuing them fully determined.* In this, as in the Physical Sciences, the first object of the philosophic enquirer is to collect a body of facts, by the comparison of which the general principles common to all may be deduced. Now the facts which the observation of living beings brings under our notice, are obviously of two kinds;—one class having reference to their *structure*, the other to their actions or *functions*. The investigation and comparison of the former class of particulars, is the object of the science of *Anatomy;* whilst by the collection and generalisation of the latter, the science of *Physiology* is built up.

4. The obstacles which interpose themselves to the prosecution of these sciences, result more from that difficulty in the ascertainment of facts and the observation of phenomena, which is occasioned by the peculiar conditions of living beings, than from any incapability on the part of

* See British and Foreign Medical Review, vol. v., p. 317, &c.

these facts and phenomena to be comprehended within laws as stable and as definite as those of the physical sciences. Thus, although the structure of the human body has been carefully and minutely examined by so many thousands of anatomists, how many points are still uncertain, and how much still remains to be discovered! Yet this structure is but one of those groups of *instances*—the Baconian term for *phenomena*—that must be collected from the many hundred-thousand species of plants and animals which the naturalist knows to exist on the surface of the globe, before we can have sufficient data for the establishment of those general and comprehensive laws, regulating the development of living organisms, which we may hope some day to arrive at. The difficulties that present themselves in the observation of the facts which it is the object of the science of Anatomy to ascertain and generalise, are as nothing to those which beset the path of the Physiological enquirer, who has to study the changes which all classes of living beings perform and undergo during the whole period of their existence. The sum of all the phenomena which constitute the Life of a single organised structure, and which result from the actions of that structure, is, in like manner, to be regarded as a collection of *facts*, of which each must be stated in a separate and concise form, before it can be made the subject of any general expression, founded upon the comparison of similar facts derived from the study of other living beings. Now the great difficulty in physiological investigation results from the complexity of the combinations in which vital phenomena present themselves, and from their dependence upon one another to a degree that almost entirely precludes their separate examination. Were we able to ascertain the changes which take place in the interior of the living body with the same ease that the astronomer watches the motions of a planet, or the chemist observes the formation of a precipitate, the very multiplicity of these changes, and the variety of the conditions under which they occur, would be of essential service in the determination of their laws, instead of being, as at present, sources of doubt and embarrassment. The chemist, when desirous of establishing to which of the ingredients in a given mixture a particular effect is due, places each separately in the conditions required to produce the result: but the physiologist finds that the attempt to insulate any one organ, and to reduce the changes performed by it to definite experimental investigation, necessarily destroys, or considerably alters, those very conditions under which alone its functions can be normally performed. Take away an important and essential part of a living being, and it ceases to exist as such; it no longer exhibits even a trace of those properties which it is our object to examine; and its elements remain subject only to the common laws of matter. We cannot, like the fabled Prometheus of old, breathe into the lifeless clay the animating fire; we cannot, by a judicious and skilful arrangement of those elements, combine them into new and artificial forms

so as to produce new and unexpected phenomena; and almost all our knowledge of the laws of Life must therefore be derived from *observation* only. *Experiment* can conduct us very little further in this enquiry than the determination of the dependence of the functions upon one another, and upon the external agents, heat, light, &c., by the action of which upon the organism the phenomena of Life are produced. But a judicious and careful system of observation will almost supply the place of experiment; for the ever-varying forms of organised beings by which we are surrounded, and the constantly-changing conditions in which they exist, present us with such numerous and different combinations of causes and effects, that it must be the fault of our mode of study if we do not arrive at some tolerably definite conclusions as to their mutual relations. In the language of Cuvier, the different forms of animals may be regarded as "so many kinds of experiments ready prepared by Nature, who adds to or deducts from each of them different parts, just as we might wish to do in our laboratories, showing us herself at the same time their various results."

5. From such considerations as these, it will be evident that the laws of Life can only be searched for, with a probability of success, by investigating their operations wherever presented to us; and that the study of Physiology can only be scientifically prosecuted, if the attainment of these laws be regarded as its ultimate object, by embracing within its range the examination of the phenomena exhibited by *all* classes of living beings. It is a great mistake to suppose that there is anything fundamentally different in the character of the vital operations as performed in the animal and in the vegetable structures, or in the simpler and more complicated organisms of either kingdom. An enlarged view of their functions, not based upon the observations of their conditions in one or two instances only, but derived from an extended examination of their performance wherever manifested, will recognise an essential conformity throughout, wherever those which are really analagous are compared. There is an obvious advantage, therefore, in commencing the study of Physiology by an enquiry into the simplest manifestations of each of those functions which in the higher organisms are so complicated in their nature. From no such enquiry should the consideration of the Vegetable Kingdom be excluded; for those vital functions which are performed by plants in common with animals, are presented by the former in a state of greater simplification than is ever exhibited by the latter; since all the changes necessary to the support of the individual and the continuance of the species, are performed without the influence or interference of those powers which are possessed in a greater or less degree by the whole animal kingdom. Hence the physiologist may advantageously resort to the study of vegetable life, for the explanation of many of the proximate causes of those phenomena which are complicated in the higher forms of

organised beings by so great a variety of secondary influences. Of the advantage of this mode of investigation, the details hereafter to be given (CHAP. XV.) on the Motions of Plants compared with those of Animals, afford a characteristic illustration. In the pursuit of his science on this plan, therefore, the physiological student will learn what are the essential conditions of life; he will see the changes indispensable to its support manifested in their simplest circumstances; he will be able to ascertain what structures are necessary to their performance, and what additions and modifications these may undergo to suit the various purposes of their existence, (see for illustration § 213 and 237); and thus he will be saved the necessity of unlearning many erroneous notions which he would unavoidably imbibe from the premature study of the complex phenomena exhibited by the living human organism. Moreover, in those departments of Physiology which are capable of being elucidated by experiment, recourse may generally be had with advantage to the lower classes of animals, and to plants; since that bond of union which links together, in the higher animals, all the changes concerned in the maintenance of the vitality of the system, is in them much less close and decided; so that particular organs may be insulated, and the study of the conditions of their actions prosecuted to a much greater extent. It is in the investigation of the effects of those external agents upon which all the phenomena of Life are dependent (§ 144), that this mode of investigation is capable of being most advantageously employed. Thus, Dr. Edwards was enabled to arrive at many important conclusions on these points, by subjecting frogs and other reptiles to treatment which would have been fatal to animals of higher character (CHAP. IX.); and Mirbel, by watching the growth of an humble liverwort (§ 61), to establish some beautiful principles as to the influence of light on the development of the Vegetable System.

6. The mass of facts which is gradually being accumulated relative to the structure of living beings, and to the vital phenomena they exhibit, must be classified and arranged, before they can become subservient to the purposes of science; and this object is accomplished in different ways, according to the nature of the laws of which the philosophical enquirer is in search. Thus the Anatomist and Physiologist, whose object it is to discover the peculiarities of organised structures, their adaptations to particular uses, and the conditions of the functions to which they are subservient, *analyse*, as it were, the group of facts which each living being exhibits (§ 4); and, pursuing their enquiries through an extensive range of objects, classify these individual results according to their similarity with each other, and their obvious tendency to the same end: or, to speak in less abstract language, they compare the *individual* organs and functions through all the forms of animated beings in which they are manifested. The object of the Naturalist, on the other hand, is to ascertain the laws which regulate the *combination* of the separate organs

into living fabrics, and govern their adaptation to different modes of existence: he, therefore, viewing each organism in its *totality*, arranges similarly formed beings into the same group, placing as the character common to the whole the points in which they agree, and leaving the subordinate differences to be added to this common character, in order to express the qualities of an individual. This classification (resembling the combination of anatomical details into descriptions of *organs*, and of physiological changes into *functions*) is but a step towards the establishment of general laws by which the structure of the organised kingdoms of nature is regulated. These laws,—expressing the manner in which the organs are combined and adapted to each other, the relative development or simplicity of each, the modifications which the typical forms (§ 129) of each group may undergo according to the circumstances in which the being is to be placed, and various other conditions of its formation,—it is the object of the Naturalist to ascertain; and any mode or system of classification which he may adopt, is valuable in proportion as it keeps the establishment of these laws in view, and facilitates the accumulation of the knowledge upon which they must be founded. The connexion between these two branches of investigation is so intimate that neither can be pursued with any probability of success, without a considerable knowledge of the data and principles upon which the other is founded; and he will evidently be the most likely to arrive at the discovery of important general truths in either, who includes the whole of the phenomena of life in one extensive survey. The Physiologist refers to the Naturalist for instances in which a function is performed on the same general plan, but under a great variety of circumstances, as manifested by the adaptation of the structure of the organ to the medium of existence, (e.g. the formation of the respiratory membrane into lungs or gills); whilst the Naturalist refers to the Physiologist to assist him, by the examination of the function and development of an organ, in determining its real character, to which the consideration of its form and structure alone might not lead him. The Natural System of Botany affords a beautiful example of this conjoint kind of investigation; and there can be little doubt, from the advances recently made, that some of the most important laws, regulating the structure of living beings, and the combination of their organs, will be speedily disclosed to view.

7. Although the object of the present treatise is the exposition of Physiological principles alone, it seems desirable to preface these by such an outline of the general structure and arrangement of the organs on which the phenomena of Life are dependent, as may render subsequent details respecting their functions more intelligible. We shall first consider, therefore, what there is peculiar in the mechanical arrangement of the particles of which organised structures are composed, and in the forms which such fabrics present. The principal varieties of the *primary* or

elementary tissues of which the more complex organs of plants and animals are constructed, will then be described and compared with one another. And lastly, the general characters of the principal groups in each of the animated kingdoms of Nature will be pointed out, the mode in which their individual organs are arranged and combined will be explained, and their relative positions displayed. Although such knowledge is readily accessible to the student of Natural History, the *embarras des richesses* may not be a little perplexing to such as seek only that extent of it which will enable them to *enter* upon the study of Physiological Science, without being immediately checked by the want of this kind of information. It will probably be more conducive to the purpose of the proposed outline, to commence it with a description of the classes which are best known; and to pass from these to others more simple, but whose structure is less generally understood, of which a more particular description will therefore be frequently required. In the portion of this volume, however, devoted to the consideration of the structure and functions of particular organs, an opposite method will be adopted; since there is an evident advantage in tracing these in their simplest manifestations, and thus determining what are their really essential conditions, before examining their more complex phenomena in beings of elevated rank in the scale of animated creation.

II.—*Of Organised Structures in General.*

8. In the production of the changes which constitute the Life of every animated being, we find an agent employed which is peculiar to the bodies that exhibit such changes, and which is entirely different from anything we observe in the surrounding universe. This agent is the mechanism which is termed *organised structure;* the designation given to it implying that it consists of separate parts or *organs*, each of which is adapted to perform some distinct part in the Vital economy. The whole organised structure of any living being is termed its *organism;* and the word *organisation* is used to imply that peculiar process by which the organism is constructed out of the materials supplied by the inorganic or mineral world, and sometimes also to indicate the state or condition of the matter upon which this process—one of the most remarkable of all the vital actions—has been effected. When we come to enquire into the nature of the functions which these organised structures perform, it will be seen that they all tend towards a common object—the maintenance of the integrity of the fabric. And it may be regarded therefore as the peculiarity of an organism, that its distinct parts or organs are destined thus to subserve, each in its own particular way, some general purpose. This, indeed, is one of the peculiarities which distinguish organised structures from inorganic matter; for in a mineral, every particle possesses a separate individuality, and whatever changes

this undergoes in obedience to physical agencies, these changes occur in conformity to laws which apply to it as well separately as in conjunction with others; whilst in a living being, the actions of all parts of the machine are so connected together, that whatever influences one single particle of the organism on which these actions depend, will more or less affect the entire system. Thus, we may suppose a mass of gold alloyed with a small quantity of silver, and immersed in nitric acid; this chemical agent will affect every particle of the silver as completely as if the mass consisted of nothing else, and will leave the gold in its previous condition, having of itself no power of dissolving it. On the other hand, a similar chemical agent applied to an organised structure, will not only destroy the integrity of the part itself, but will produce a disturbance of the general functions proportional to the importance of the organ which has been injured; whilst the influence of any of the ordinary external agents by which life is maintained (see CHAP. II.) is exercised not only on the parts or organs with which they are in immediate relation, but through them on the whole structure.

9. But it may be said that this is no more than takes place in any engine of human construction, or in the complicated machine of the universe,—that in these, as well as in living bodies, there is an adaptation of parts to each other, and of their actions to some general purpose, —and that all forms of matter are possessed of properties by the mutual influence of which, changes may be produced, as regular and as ceaseless as those which living beings exhibit. Thus, the uniform motions of the heavenly bodies, the alternation of the seasons, the continual alterations which the crust of the earth is undergoing, the earthquakes and volcanic eruptions which so remarkably excite our attention to those alterations, and which may be regarded as more prominent indications of the same latent causes, the successive evaporation and condensation of the watery covering of the globe, the perpetual variations in the force and direction of the wind, the occasional recurrence of those violent meteorological changes which spread terror and desolation wherever they occur, but which serve such important purposes in the economy of Nature—all these phenomena, and many more which might be instanced, result, no less than the constant changes exhibited by the animated creation, from that adaptation of parts to a whole which is so characteristic of design in the universe at large. Hence some philosophers have gone so far as to embody these phenomena into a general expression—the Life of the World; and as far as the abstract meaning of the terms is concerned, it would be difficult to show that a single piece of mechanism, or the entire universe, is not *organised* as completely as any animated structure. But a little consideration will show that in the construction of a machine, man avails himself only of the ordinary or physical properties of matter; and that in the most complicated arrangement of its parts, each single

element possesses only the same capabilities as it would have if separated from the rest. Thus the moving power of a clock is given by the gravitation of a weight,—that of a watch by the clasticity of a spring,—that of a steam engine by the expansion and condensation of watery vapour; and all the rest of the mechanism is contrived only to give effect to these agencies by employing them in the manner most advantageous for the designed end. In the phenomena of the universe, again, we see nothing but the agency of the ordinary physical properties of matter. Thus the motions of the solar system all result from that universal property of matter—gravitation—which, originally balanced against other forces, will continue to produce the same effects as long as may be consistent with the designs of the Creator. By these motions are produced all the variations of climate and season in our own globe; and from the same property which causes them, results the constant movement of the waters of our ocean. By the heat of the central luminary, again, are probably occasioned, either directly or indirectly, most of the atmospheric changes which are of such consequence to the well-being of the plants and animals which people this earth; and the same agent has a most important and immediate influence on the phenomena of their growth and decay. Further, it appears probable, that the supposition of an internal heat in this globe itself, coupled with the known effects of solar heat, oceanic movements, atmospheric changes, and other external agents upon its surface, (among which the influence of living beings is by no means the least, as the formation of coral reefs and islands sufficiently exemplifies,) will ultimately explain the constant changes which its crust is undergoing.

10. But it is only where different material bodies are brought into a relation with one another, by which their properties are called into action, that these changes are exhibited; and so long as any mass of inorganic matter is placed out of the pale of their influence, it may remain perfectly unchanged for an indefinite period. In the mineral or inorganic world, therefore, *change* is the *exception*, and *permanence* is the *rule;* whilst in the animated kingdoms, *change* is constant and universal, and is indeed essential to our idea of life (§ 1).* When we compare, therefore, the constant changes which we encounter in living organised beings with the inert state of inorganic matter, we are compelled to conclude, that to whatever extent the forces which control the latter contribute to the actions going on in the former, there must be additional forces resulting

* It is true that there are certain cases in which organised structures have remained perfectly unchanged for centuries, without losing their peculiar properties (§ 155-7), and we have no reason to believe that there is any limit to the period during which they might thus exist. But it will be shown that this can only occur when they are not merely removed from the influence of those stimuli which would rouse their dormant vitality into active life, but are also placed out of the sphere of those decomposing agents, whose power would occasion the separation of their elements and the consequent loss of their vital properties.

from the operation of properties to which we know nothing analogous elsewhere. The degree in which these superadded forces harmonise or interfere with those common to other forms of matter, constitutes a fair and highly interesting branch of enquiry which will hereafter be pursued. (CHAP. I.) But it is at present sufficient to state, that since these properties are never exhibited by any forms of matter except those usually denominated organised, our notion of an organised structure is founded not only upon the adaptation of its parts to one another, but upon the indisputable possession by each part, of independent properties, by which it is enabled to execute actions for which physical laws will by no means account. And the process of organisation implies, therefore, not only the conversion of the homogeneous materials into regular and complex structures, but the simultaneous endowment of them with vital properties.

11. Although in every animal and vegetable fabric there are many different kinds of organised tissue, differing from one another both in structure and properties, and although these again present differences according to the class of beings in which the examination is made, yet there are certain general peculiarities by which all are seen to be characterised, when contrasted with mineral or inorganic bodies; and these peculiarities are as manifest in the humblest and simplest member of the animated creation, as in the most elevated and complex. It has been a favourite attempt amongst many naturalists, to trace a regular gradation or scale through the whole material universe; and not only to prove that the line of separation is indistinct between the animal and vegetable kingdoms, but to show that there is not such a complete division between the organised and inorganic world as physiologists think themselves justified in erecting. It is doubtless true, that the discoveries of modern science are constantly bringing to light connecting links which were previously deficient in many parts of the chain; and that, in particular, an increased acquaintance with the various races of animals and vegetables which formerly inhabited this earth, through many successive epochs, seems likely to fill up whatever chasms are left open between the groups at present existing. But it is no indication of a philosophical spirit to attempt to discover relations where none can by possibility exist. The simplest of the aerial flags, such as the *red snow*, or the *gory dew* (§ 69), as well as the most minute and, apparently, least complex animalcule, exhibits, when carefully examined, all the characteristics of organised structure, as well as all that can be regarded as peculiar in vital actions. They grow from a germ, increase, reproduce their kind, die, and decay, as regularly as any of the higher members of their respective kingdoms; and they present the same peculiar and definite arrangement of particles, the same combination of fluid and solid materials, the same mutual adaptation of organs, as the latter possess.

12. However close, therefore, may be the links by which the animal

and vegetable kingdoms are connected together, the relation is only a mutual one; and between organised fabrics, and the products of crystallisation, (or of any other mode of aggregation by which inorganic matter is held together, in masses great or small,) there is a total want of resemblance. In this instance no analogy can be traced, except what is vague and chimerical. The absurd speculations of Robinet—who described all matter as possessed of living properties, and who regarded every object in existence, whether mineral, vegetable, or animal, as resulting from the repeated efforts of nature, becoming only progressively successful, to form man—can now only excite our pity and contempt. Yet this doctrine has been advocated by many continental authors, who have even represented the fantastic forms assumed by many minerals, and bearing some resemblance to different parts of the human body, as so many proofs of this long and bungling apprenticeship of nature to the art of man—making; and there are philosophers, even at the present time, who hold doctrines, which, if cleared from their veil of mysticism, and expressed in ordinary language, would probably be found to be not dissimilar.* To show in what the state of organisation essentially consists, it will be necessary to contrast, in more detail, the peculiarities common to all beings which exhibit it, with the condition of inorganic or mineral bodies.

13. Wherever a definite *form* is exhibited by mineral substances, that form is bounded by straight lines and angles, and is the effect of the process termed *crystallisation.* This process results from the tendency which evidently exists in particles of matter, especially when passing gradually from the gaseous or fluid to the solid state, to arrange themselves in a regular and conformable manner with regard to one another; and there is, perhaps, no inorganic element which is not capable of assuming such form, if placed in circumstances adapted to the manifestation of this tendency among its particles. The mineralogist is conversant with an immense variety in the forms of crystals; these, however, may all be reduced to a few primary types, from which the mathematician can deduce the rest. But, on the other hand, if the particles be not placed in circumstances favourable to this kind of union, and the simple molecular attraction, or attraction of cohesion, is exercised in bringing them together without any general control over their direction, an indefinite and shapeless figure is assumed. Neither of these conditions finds a parallel in the organised creation. From the lowest to the highest of living beings, the shape is determinate for each individual, —not only as a whole, but even as to each of its component parts; and instead of being circumscribed within angles and right lines, organised

* See a Memoir on the Kingdoms of Nature, their Life and Affinity, by Dr. C. G. Carus, translated in Taylor's Scientific Memoirs; and the ingenious but vague "Philosophie de l'Histoire Naturelle" of M. Virey.

fabrics usually present a rounded outline and convex surface. It is true, that in the vegetable kingdom, and to a certain extent among animals also, we find a considerable difference in the external forms of objects of the same species; but this difference is restrained within certain limits, and may usually be referred to the influence of external causes. Although, as has been stated, the characteristics of organisation are never so far absent from the living structure as to indicate a transition to the mineral world, it is interesting to remark, that, as we descend in the scale of animated creation, we find these peculiarities less striking. And with regard to *form*, it may be observed, that this seems least definite among the Sponges and Polypifera (coral-formers) among animals, and among the lowest groups of cellular plants among vegetables; and that there is reason to believe that among these the same germ may assume a variety of distinct forms according to the circumstances under which it is developed, just as the same mineral substance may present itself under a diversity of crystalline shapes.

14. With regard to *size*, again, nearly the same remarks apply; since the magnitude of inorganic masses is entirely dependent on the number of particles which can be brought to constitute them, and is therefore completely indeterminate; whilst the size of living beings is restrained, like their form, within definite limits, which vary to a certain extent in each individual. And, as in the former case, the *size* to which the inferior members of the animated kingdoms may increase, seems but little restricted in comparison with that of the higher classes; so that it is of no uncommon occurrence for some species of sea-weed to attain a length of many hundred feet; and in those enormous masses of coral which compose so many islands and reefs in the Polynesian Archipelago, or of which the *debris* seem to have constituted many of the calcareous rocks of ancient formation, it would be almost impossible to ascertain the limits to which a single individual might extend itself.

15. Having considered the external form and size, we have now to compare the internal arrangement or *aggregation* of the particles respectively composing organised structures and inorganic matter. And here we at once meet with a striking and remarkable difference. Every particle of a mineral body may exhibit the same properties as those possessed by the whole; and if there is a variation, it results only from an impurity or admixture of some other body. The chemist, in experimenting with any substance, cares not, therefore, except as a matter of convenience merely, whether a grain or a ton be the subject of his researches. The minutest atom of carbonate of lime has all the properties of a crystal of this substance, were it as large as a mountain. Hence we are to regard a mineral body as made up of an indefinite number of constituent particles, similar to it and to each other in properties, and having no further relation among themselves than that

which they derive from their juxtaposition. *Each particle* may be considered, therefore, as having a *separate individuality.* The living body, on the other hand, whether of a plant or animal is made up of a number of organs, each of which has a peculiar texture and consistence; and it derives its character from the whole of these collectively. By their action with each other, and with external agents, life is produced; and hence there is a relation between their elementary constituents much closer than that of proximity only, namely, that of mutual dependence; so that as no one part can continue to exist without the rest, it cannot be regarded as possessing that separate individuality which belongs to the whole system alone. Thus, the perfect plant which has roots, stem, and leaves, is an example of an organised structure in which the relation of every part to the integrity of the whole is sufficiently obvious, since every one is aware that, if completely deprived of any of these parts, the plant will perish unless endowed with the power of replacing them; and no one portion separated from the rest can long continue its functions. But yet, in the plant, many of these organs are but repetitions of each other, so that some may be removed without permanent injury to it, provided enough are left to maintain its present existence. In the more highly organised animal structures, however, where the greater diversity of organs forbids such repetitions, the mutual dependence of their actions upon one another is much greater, and the loss of a single part is much more likely to endanger the existence of the whole. But when we look at the lower classes of plants and animals in this point of view, it is often very difficult to fix the limits of their individuality. Thus there are some even among the Mollusca (§ 104) which unite together into aggregate masses during one period of their existence, and separate at another. And among the Entozoa and Radiata, there are many which are so entirely composed of repetitions of the same parts, that they may be multiplied by subdivision. There are among the Sea-weeds also, and especially among the fresh-water Confervæ, many species in which several similar parts are united together for a time, and afterwards spontaneously separate, so as then unquestionably to become distinct individuals. Even among the higher plants, as among the Polypifera, which so much resemble them in their mode of growth and increase, it may reasonably be enquired if every bud is not to be regarded as a separate individual, since each is capable (like the polype) of maintaining its own existence when removed from its parent structure. It may be found not altogether an incorrect or unnatural representation of the gradation which exists in this character, to say—The *individuality* of a mineral substance resides in each molecule; that of a plant or inferior animal, in each member; and that of one of the higher animals, in the sum of all the organs.

16. The next point of difference between organised structures and

mineral bodies is their *consistence.* Inorganic substances can scarcely be regarded as possessing a *structure*, since they are exclusively made up of one form of matter, which—whether solid, liquid, or gaseous—is uniform or homogeneous throughout, being composed of similar particles held together by attractions which affect all alike. It may be objected to this statement, that there are solid mineral substances to the crystallisation of which water is essential, and others which inclose it within cavities: but in the first of these cases, the water becomes solidified, being chemically united with the substance; and in the second, its presence is merely accidental. Far different is the organised structure of living beings; for in this may be detected an arrangement of the ultimate particles very different from that which crystallisation produces;* and it is always composed of a mixture of solid and fluid elements which are so intimately combined as to produce a degree of flexibility and tenacity strongly opposed to the rigidity and brittleness of mineral substances. And it will be noticed that, wherever it becomes necessary that for the support of the fabric an extraordinary degree of firmness should be given to any portion of the structure, this quality is imparted by the deposition of earthly or saline particles, which frequently retain their crystalline form, and are evidently subject to no laws but those of physics and chemistry (§ 41). Thus we have carbonate of lime diffused through almost all the tissues of plants, and a copious deposition of silex beneath the surface of the grass tribe, where lightness is to be especially conjoined with strength. It has been lately shown that so universally do the tissues of plants receive support from these inorganic elements deposited in their interstices, that, if the organised portion of the structure be carefully destroyed by the agency of heat, an earthy skeleton will remain in which the forms of all the parts will be distinctly marked out. In animal structures, earthy depositions are usually more concentrated into particular spots, especially where the locomotive powers are considerable; since it is obviously essential to the exercise of those powers, that whilst the framework which gives attachment to the organs of propulsion should be solid and unyielding, these organs themselves, as well as other parts of the fabric, should be capable of great freedom of action. In the higher animals, therefore, we find carbonate and phosphate of lime deposited in special situations, so as to give a firm basis for the attachment of softer structures; the former ingredient predominating where the skeleton is massive and external, as in the Mollusca in general; the latter where it is enclosed within the softer parts, and where concentration of bulk

* It has been a favourite doctrine on the part of many Physiologists that the ultimate particles of organised tissues have always a *globular* form; there is little doubt, however, that this statement is partly based on an optical illusion; and it seems most satisfactorily refuted by Ehrenberg, who has shown that there are animalcules of complex structure more minute than the so-called ultimate globules.

without diminution of strength, is therefore an important object. But there are some among the lowest, in which the adaptation for locomotive powers is no object; and here we find the structure even more universally penetrated with calcareous matter, than that of vegetables. Thus the masses of coral, which are produced by the action of a soft and almost jelly-like animal structure, were long supposed to be the habitation of the numerous little beings which form them, rather than a portion of their own structure (§ 119). Moreover, it is in the parts in which depositions of this kind take place, that vital changes are least actively performed; and we find the bones of animals, and the woody fibre of plants, to be the portions of their respective structures which resist decay the longest, and thus rank nearest to mineral substances. While, on the other hand, it is by the softest tissues that the most active functions are performed; and these frequently lose by subsequent consolidation the properties which rendered them capable of such important duties. Thus, the *spongioles* of plants, by which the nutritious fluid is introduced into their vessels (§ 248), are nothing but the newly-formed succulent extremities of their rootlets; and, when condensed by the addition of new materials, they become embodied into the substance of the root, and transfer their function to fresh prolongations of the fibres. In like manner, the cartilages of animals become consolidated by the advance of life, and their elastic pliancy gives place to rigid density. And that texture of which the offices are most important, and the furthest removed from any thing analogous in the external world, the nervous matter—is the softest and the most decomposable of all the tissues of the body, and is constantly being renewed (if we so may judge of the object of the vast quantity of blood with which it is supplied) in the living body, in proportion to the demands upon its exercise. While solidity or hardness, therefore, may be looked upon as the term of perfection in the mineral kingdom, softness often appears to be the peculiar characteristic of the most important vital or organised structures; and this results from the large quantity of fluids which enter into their texture.

17. A peculiarity in respect to their chemical constitution is usually regarded as belonging to organised structures. This point being at present made the subject of zealous enquiry on the part of many distinguished philosophers, and great difference of opinion existing among them, it seems advisable to state in this place only what is positively known. Of the elementary constituents of living bodies, it may be observed, in the first place, that no substance is found in them which does not also occur in the world around. This fact is a remarkable one; but a little consideration will show that it is a necessary result of the mode in which their structures are organised, or, as it were, built up of the materials supplied from external sources. For the parent communicates to its offspring, not so much the structure itself, as the power of forming

that structure from the surrounding elements. Of the 54 simple or elementary substances which occur in mineral bodies, only about 18 or 19 are found in plants and animals, and many of these in extremely minute proportion, although perhaps not on that account in a state of less activity (§ 500). Now with regard to these it may be observed that, while the bulk of the inorganic world is made up of the metals and their compounds, (which form the alkalies, earths, and some of the acids,) the essential ingredients of living bodies appear to be four of the non-metallic elements, viz. oxygen, hydrogen, nitrogen, and carbon; of which the first three in their uncombined state have a gaseous form. Of these, carbon may be regarded as the most characteristic ingredient in the composition of vegetables, and nitrogen in that of animals: it was formerly supposed that the latter very rarely exists in the vegetable kingdom, but further research has shown that it is much more extensively diffused than was believed, though usually present only in small proportion. Scarcely any of the 54 elementary substances are found in an uncombined state in nature; most of them exist in union with others; and in some the tendency to remain thus combined is so strong that they can with great difficulty be obtained in a free state. Indeed of one—Fluorine—it may be said that it has never yet been obtained in a separate form, since its tendency to combine with all other bodies is so powerful, that there is no one of them, not even platinum, with which it does not unite if brought in contact with it. Its properties can therefore only be judged of from its observed effects, and from the analogies which it presents to other elements. Now this tendency to combine with other bodies, or in other words this *affinity*—a term which we must be careful not to employ as signifying a distinct or separate force, being only the expression of a *property* of certain forms of matter,—is possessed by all simple substances in a greater or less degree. It is by its action that compounds are formed, and that these compounds have a tendency to unite with one another. It is by the operation of affinity, also, that compounds already in existence are decomposed; a new and more powerful set of forces being brought into action by the change of circumstances, which occasions the separation of the elements that have the weaker attraction for one another, and their reunion into other compounds where they are more firmly held together.

18. In forming our opinion as to the nature of the affinities by which the elements of living tissues are held together, it is important to recollect that those which are regarded as strictly *chemical*, (being, in fact, the result of the electrical properties of bodies), are very much affected by temperature and other external influences, so as even to be reversed by them. Thus potassium at low degrees of heat has a much stronger affinity for oxygen than iron, and to obtain oxygen will decompose almost any substance into which it enters; but at a white heat, the

affinity of iron is so much greater that it will decompose potassa (the oxide of potassium) and, by subtracting the oxygen, will leave the metal in an uncombined state. The affinity of mercury for oxygen is affected in the contrary manner by heat,—this metal being oxidised by contact with the air when near its boiling point, but losing its affinity for oxygen at a higher temperature. It is scarcely a sufficient argument, therefore, for the existence of a set of vital affinities, distinct from those which hold inorganic substances in combination, to say that all organised tissues exhibit a tendency to spontaneous decomposition by the separation of their elements, or by their dissipation under simpler forms, immediately upon the loss of their vitality. That this is a usual occurrence, every one knows; and it is so obvious as to have given rise to the well-known definition of *life*, that it is the power by which decomposition is resisted. But the inference from it—that the affinities which hold together the elements during life are of a different nature from those which operate in producing their subsequent separation—appears scarcely entitled to the character of a positive law. For it may be readily shown by a reference to well-known physiological facts, that no solid or fluid compounds which have a disposition to spontaneous decay after death, can continue to exist without change during life; and that the activity of the processes of interstitial absorption (CHAP. VII.) and reposition (CHAP. VIII.) seems to bear a pretty constant ratio in every case with the natural tendency to separation. So that the maintenance of the original combination may be owing, not so much to anything peculiar in its *vital affinities*, as to the constant provision for the removal of particles in a state of incipient decay, and their replacement by others freshly united by the peculiar operations of the living system, the nature of which will be hereafter considered. Thus, we find that all the most permanent parts of the animal frame, such as the massive skeletons of the Polypifera, the calcareous enclosure of the Mollusca, the bony scales of Fishes, &c., all of which are believed by geologists to have remained nearly unchanged for thousands of centuries, are completely *extravascular* in the living animal, that is to say, not permeated by nutritious or absorbent vessels, and undergoing no interstitial change when once formed. Next to these in order of durability, are the osseous structures of animals, and the woody fibre of vegetables, whose connection with the nutritive system appears rather adapted to meet the exigencies of growth, injury, or disease, than to maintain a constant change required by the tendency to decomposition. When we examine the softer tissues, on the other hand, we find that the rapidity of interstitial change fully compensates for the increased tendency to decay; but that if this change be, from any cause, prevented, decomposition and loss of vital properties ensue,—as in the case of spontaneous gangrene from obstructed circulation. It is interesting to remark also, that the liberation of carbonic acid, which begins so soon

after death, and is one of the first signs of putrefaction, is the most constant and necessary excretion of the body during life, being thrown off not only by the special respiratory apparatus, but also by the general surface. It might further be argued against the doctrine of a distinct set of vital affinities, that the circumstances under which organic compounds exist in the living body differ in so many particulars from those of dead matter, that no conclusion could be fairly drawn from the fact of their spontaneous decomposition after death; since inorganic chemistry affords so many examples of the occurrence of similar changes, under the influence of very slight variations in temperature, electrical condition, light, &c.

19. It has usually been maintained that in the composition of inorganic substances, the elements unite together in a *binary* arrangement, and in a relation which admits of being very simply expressed; and that all the more complex arrangements admit of being resolved into this simple form. Thus, sulphur and oxygen unite in the proportion of 1 to 3, to form sulphuric acid; and sodium and oxygen in the proportion of 1 to 1, to form the alkali soda; equivalents of each of these, if brought together, unite to form the salt termed sulphate of soda; and this salt may unite with some other of analogous composition to form a double salt. On the other hand, it is usually believed that the *proximate principles*, as they are termed, of organic compounds, (that is to say, the simplest forms to which these compounds can be reduced, without altogether disuniting them into their ultimate elements), consist of three or four ingredients united together in a relation of much complexity. Thus, an equivalent of the vegetable alkali *quinine* is made up of 21 eq. of carbon, 12 eq. of hydrogen, 1 eq. of nitrogen, and 2 eq. of oxygen. But on this it may be observed, that there are undoubtedly some proximate principles which consist of two elements alone; as for instance, the compounds of hydrogen and carbon which exist as such in living bodies. Again, our ignorance of the appropriate means of analysis is very likely to lead us astray; since there is no improbability, but, on the other hand, an almost positive certainty, that most of the more complex organic substances might be resolved into simpler compounds, if the chemist knew how to treat them. Let us compare for example the two instances just quoted. If the chemist were at once to analyse the sulphate of soda into its ultimate elements, he would find it made up of 1 eq. of sulphur, 4 eq. of oxygen, and 1 eq. of sodium. Were this all that he knew of its composition, he would be at a loss to say how the oxygen is distributed between the other elements. But knowing, as he does, that the salt contains two binary compounds which he can separately examine, he may say with confidence that the oxygen is distributed between the sulphur and the sodium in the proportion of 3 to 1.* Now it is obvious

* I have thought it better to keep to the usual opinion on the composition of salts, though by no means insensible to the beauty of the new doctrines which have been lately offered.

that as long as compounds like quinine remain in their original state, we must be in total ignorance of the method in which their elements are united: but the progress of analytical research undoubtedly tends to indicate that such complex arrangements may be resolved into those of a simple binary character; and with regard to the vegetable alkalies in particular, it is now generally admitted that they owe their power of neutralising acids to the ammonia which enters into their composition. Again, camphor, which was long regarded in the light of a proximate principle, and which consists of 8 hydrogen, 10 carbon, and 1 oxygen, is now found to be an oxide of *camphene*, a compound radical of binary composition, which will unite with another equivalent of oxygen to form camphoric acid, and with chlorine, &c. into other compounds. Many similar instances might be adduced; and it seems an unquestionable fact that every fresh discovery is tending to break down the barrier between the two classes of organic and inorganic bodies, as far as regards their method of chemical combination.

20. Investigations into the elementary arrangement of the parts which primarily compose organised structures, are often attended with much difficulty and liability to error. The minuteness of the objects which are to be examined, and the changes which may be produced in them by the preparation they are necessarily made to undergo, before being submitted to microscopic inspection, not to mention the deceptions arising from imperfection in the instrument itself, or the mode of employing it, have led to much discrepancy in the statements of different observers. Too often the descriptions given have not been of what has been actually seen, but of what has been imagined; and have, without any intention of falsifying them, been shaped according to the preconceived notions of the enquirer. Hence, an examination of the characters of the primary tissues, whether of plants or animals, requires not only considerable manual skill and dexterity in the use of the microscope, but an acquaintance with all the fallacies arising from the difference between the image presented to the eye, and the object as it exists in its natural situation; besides what is even more important, a perfect readiness to give up preconceived notions, when they are inconsistent with observation, and a determination to consider nothing as proved until every mode of investigation has been employed with the same result. In the brief outline which will now be given of the characters of the principal elementary structures occurring in the fabric of plants and animals,

(See Graham's Elements of Chemistry, p. 158, &c.) To those who are acquainted with these, it will be evident that their tendency is to indicate a still greater resemblance than that here pointed out between organic and inorganic compounds; the sulphate of soda being on this view formed by the union with sodium of the compound radical *sulphatoxygen*, which is regarded as analogous with cyanogen, and as combining, like chlorine, iodine, &c., with the metals and other bases.

care will be taken to distinguish what is actually seen, from the theoretical ideas of the conformation of the parts to which such observations lead. And it will be an especial object of enquiry, how far such an analogy may be traced between these characters, as to lead to the belief that any of the tissues, whether peculiar to the two kingdoms respectively, or occurring under different forms in both of them, are constructed upon the same plan.

III.—*Elementary Structure of Vegetables.*

21. All the elementary or primary tissues of plants may be considered as formed of *membrane* and *fibre*, either separately or conjoined; it may, however, be doubted whether even these are to be regarded as distinct elements, or whether they may not be formed by the adhesion of single globules, sometimes in expanded surfaces, sometimes in lines only. Although they frequently occur in combination, membrane is often found without any trace of fibres, and sometimes fibres may be seen without any membranous envelope. Instances of their union may be seen in spiral cells (Fig. 5), or in spiral vessels (Fig. 12); and of their separate existence, in the simple membranous cell (Fig. 1), or in the curious spiral fibre surrounding the seed of the *Collomia*.* Vegetable *Membrane* is of variable thickness and transparency, and though very permeable to fluids, is entirely destitute of visible pores. Many botanists have described the existence of apertures in the membrane of which some forms of cellular tissue are composed; but sometimes these appearances seem to be produced by grains of semitransparent matter adhering to the membrane, and may be removed by immersing it in nitric acid, which renders them opaque, after which, immersion in a solution of potash will restore them to their previous degree of transparency; and in other instances they are probably due to a diminution in the thickness of the membrane in those spots, from causes which will be presently explained. Elementary *Fibre* may be compared to hair of extreme tenuity, its diameter often not exceeding the $\frac{1}{12000}$ of an inch. It is generally transparent and colourless; it is usually disposed in a spiral direction (Fig. 14), and its adjacent threads seem to have a peculiar tendency to unite and grow together (Fig. 16). Some observers maintain that it is hollow, others that it is solid; a question involving the conditions of a body of such extreme minuteness, however, is not easily determined.

22. The forms under which these elements and their combinations

* This beautiful microscopic object is to all appearance like other seeds; but on the outside of its coats there is a congeries of elastic spiral fibres, which, in the ordinary state, are agglutinated by mucilage, and pressed together so as not to be perceptible. Immediately as the seed is wetted, however, the mucilage is dissolved, and their elasticity causes them to spring out with great rapidity. Some other seeds, as those of the *Salvia Verbenaca* (Wild Clary), have a similar property.

most frequently present themselves, may be thus classified. 1. *Cellular Tissue.* 2. *Woody* or *Fibrous Tissue.* 3. *Vascular Tissue.* It will be shown, however, that they may all be regarded as modifications of the same elementary forms; since they are all developed in the young plant from a common origin, and in the adult structure many intermediate links are found which connect them by almost imperceptible transitions. Still it is important for practical purposes to distinguish these different forms of tissue; since, when once fully formed, they do not appear susceptible of mutual transformation, and their functions in the economy of the plant are entirely different.

23. That which may be regarded as the most characteristic example of cellular tissue, exists in most pulpy fruits, as well as in the pith and other soft parts of the structure. It is simply a vesicle or minute sac of a globular or spheroidal figure, containing fluid to which its colour, if it presents any, is due, the membrane of which it is formed being transparent and colourless; thus, in the pith this tissue is white, in the leaves green, and in the petals of flowers it may be variously coloured. From its being composed of membrane alone, it is called *membranous cellular tissue* (Fig. 1). The rounded form is only exhibited when the vesicles are but loosely aggregated together, and it is then that the distinctness of their sides is most evident. When the tissue is more solid, the sides of the vesicles are pressed against each other, so as to become flattened, and to be in close apposition; and sometimes they adhere in such a manner, that the partition between two adjacent cells seems to be but a single instead of a double membrane. If the pressure to which the vesicle is subject be equal in all directions, the form it will assume is that which is mathematically termed a rhomboidal dodecahedron, that is to say, a twelve-sided solid with all its faces equal, and showing an hexagonal section when cut across. Each cell will thus be in contact with twelve others, which completely surround it without leaving interstices. It is not very often, however, that this form is displayed with such extreme regularity; since there is usually in the growing plant a disposition to elongation in the direction of increase, and to compression in the transverse one, so that the cells are found to have rather a prolonged form. Such are especially found in the lower tribes of plants, which have no other kind of tissue, and are destitute of vessels, the function of which is partly performed by them. Not unfrequently, cellular tissue is found to possess a cubical or prismatic shape, especially in pith (Fig. 2); and occasionally the vesicles are arranged in regular horizontal rows like the bricks in a house; this last, which is called *muriform* cellular tissue (Fig. 3), enters into the structure of the medullary rays (§ 51); and the horizontal elongation of the cells which is peculiar to it, appears to contribute to an important function of the vegetable economy. Fluids which penetrate this tissue, always pass most readily in the direction of the

greatest length of the cells; and whilst, in the growing plant, the elongation of the cells, in those parts of the stem through which the upward current of sap passes, is always vertical, the downward current, which has to be conveyed from the bark to the interior of the stem, traverses these horizontal cells, which are sometimes so much lengthened as to resemble tubes (Fig. 4). But the vesicles of cellular tissue do not always consist of simple membrane; and two other kinds of cells may be noticed, not so much because interesting or important in themselves, as because they assist in explaining the character of other kinds of tissue. One of these is the *spiral cell* (Fig. 5), which consists of a membranous vesicle having a fibre coiled spirally around its interior; this form of tissue is occasionally met with in the coverings of winged seeds, and constitutes the entire plant of the Moss Sphagnum. Sometimes the fibre adheres so closely to the membrane that it cannot be separated, and the cell seems as if it were formed of a spirally-coiled fibre alone; but this may probably be due to the intimate union of the two elements. Another kind of vesicle occasionally met with, is that termed the *dotted cell*, of which specimens are shown in Fig. 6, chiefly derived from Orchideous plants. This is a very interesting kind of structure with reference to the explanation of others. The cell marked *a* is one which would formerly have been supposed to possess pores or apertures in its membranous sides; but the true nature of these seems to have been satisfactorily determined by the comparison of other forms intermediate between it and the spiral cell just noticed. Thus, a cell presenting similar dots is seen at *b*, where they are shown to be spaces intervening between the coils of the spiral fibre, which is adherent to the membrane so closely as to form a sort of inner coat deficient at these spots, where the membrane alone forms the wall of the cell. This is evidently, therefore, a transition form between the *spiral cell* (Fig. 5), and the *dotted cell* (Fig. 6, *a*) which would at first sight have appeared quite different in character.

24. The size of the cellules of this tissue is very variable; they are usually from $\frac{1}{300}$ to $\frac{1}{500}$ of an inch in diameter, but may be found of all sizes from $\frac{1}{30}$ to $\frac{1}{3000}$ of an inch. Although other kinds of structure are mixed up with it in flowering plants, it may be regarded as constituting, either in itself or in its most simple modifications, the great bulk of the organs in which active vital processes are being performed; and in the greater part of the Cryptogamia, no other is found. It is capable of growth in all directions, and it consequently fills up the interstices left by the more solid parts of the framework with a softer structure, which may be regarded in some measure as analogous to the flesh of animals. This is usually termed *parenchyma*, and a good illustration of it may be found in leaves, where the beautiful skeleton formed by the reticulation of the veins, (which may be separated by maceration from the general substance of the organ), gives support to the intervening tissues. Although fluid

generally finds its way with tolerable facility through cellular structure, especially in the direction of the greatest length of its cells, a more direct means of connection between distant parts is required when the circulation is active (§281). This is afforded by what has been termed *Vasiform tissue*, which consists merely of cells laid end to end, the partitions between them being more or less obliterated, so that a continuous tube is formed. The origin of this kind of tissue has been much disputed; and many writers regard it as a modification of vascular rather than of cellular structure, since traces of a spiral fibre may often be seen upon its sides. It is, however, so common to see the remains of the partitions which originally closed the ends of the individual cells, disposed at intervals along the ducts (Fig. 7), that it is impossible to avoid admitting that they are generally, at least, produced in this manner; and we occasionally find not only *dotted ducts* (Fig. 8) and even spiral ducts, but vessels formed by the aggregation of simple cells (Fig. 9). The vasiform is the largest of all kinds of tissue, and may frequently be detected with the naked eye, when its open mouths are exposed by a transverse section, as in the vine or cane; it is frequently pervious for a considerable length, especially in cases where the rapidity of vegetation and the length of the stem render a rapid transmission of the fluid necessary. There is a very evident analogy between the mode of development of these canals, and that of vessels in the animal structure, which appear to be first formed by a similar junction of minute cavities in particular lines.

25. Ligneous tissue or *woody fibre* consists of very slender transparent membranous tubes, usually tapering at their extremities, collected into bundles, and generally having no direct communication with each other except by invisible pores (Fig. 10). Mr. Slack* and Dutrochet,† however, state that they have seen evident communications between the extremities of the tubes; these are scarcely, perhaps, to be considered as of regular occurrence, but rather as the occasional results of the rupture or obliteration of the membrane by pressure. Although we find so many intermediate forms between woody fibre and cellular tissue, that there is no difficulty in tracing the gradual elaboration of the former from the latter, yet the characteristic forms of the two structures differ considerably. Woody fibres, like the vesicles of cellular tissue, are closed sacs: but whilst the latter have more or less of a rounded shape, the former are elongated and attenuated so as to present altogether a different appearance; at the same time they acquire a greatly increased density and firmness, although the membrane which forms their walls is really much thinner. It will be readily perceived that, independently of the difference in the tenacity of this membrane, a structure composed of woody fibre will bear a much greater tension than one formed of cellular tissue, from the advantage gained by the situation of the tubes with regard to each

* Trans. of Soc. of Arts, vol. xlix. † Mem. Anat. et Physiologiques, tom. 1, p. 121.

other; thus, threads of hemp and flax, each of which is a small bundle of woody fibres, are far stronger than those of cotton of similar diameter, which are composed of cells laid end to end. A peculiar form of woody fibre is found in the stems of the *Coniferæ* (fir tribe); no dotted ducts exist in them, and the diameter of the woody fibres is much greater than usual; along each of them is perceivable with the microscope a row of large dots, which appear to be formed by the adhesion of some little bodies to the interior of the tube. This curious structure, shown at Fig. 11, has enabled botanists to determine that many remains of fossil woods, especially those of the coal formation, belonged to this order; and as the mode in which these dots are arranged exhibits variations, each of which is peculiar to some division of the order, the fossil specimens may be closely compared, by their stems alone, with those of the present epoch. Woody fibre is apparently destined for conveying fluid in the direction of its length, and for giving firmness and elasticity to the parts of the fabric which require support. Wherever vascular structure exists, it is protected by bundles of this tissue; and hence many parts in which they are united, such as the veins and footstalks of leaves, are spoken of as being composed of *fibro-vascular* tissue. In all plants with permanently elevated stems, this tissue is very abundant; but it is not discoverable in any below the Ferns, and it exists in but small amount in herbaceous plants. It may therefore be regarded as constituting the essential organ of support in all the orders of the vegetable kingdom; and when no longer required for the conveyance of fluid, additional firmness and toughness are given to it by the deposition of various secretions within its tubes, constituting the difference between the *duramen* or heart-wood, and the *alburnum* or sap-wood (§ 51). After the deposition just mentioned has taken place, woody fibre seems to be removed from the active functions of vegetation, and to undergo but little change for an almost indefinite period. It is therefore somewhat intermediate in character between the bony structures of the higher animals, which maintain a constant relation to the processes of nutrition by means of their circulating and absorbent systems, and the unorganised parts of their fabric, such as the hair and nails, or the shells of Mollusca and Crustacea, which, when once formed are independent of any further vital changes. Perhaps cartilage is of all the animal tissues that which bears the greatest analogy to woody fibre; owing, like it, the density which it possesses, to the deposition of a secretion (albumen) in the minute cavities of a modified form of cellular tissue.

26. The third kind of elementary structure in plants is that which is denominated *vascular tissue.* Its essential character is the possession of a spiral fibre coiling within its membranous tubes from end to end; but this fibre is not always to be traced with the same distinctness, and sometimes the appearance presented is rather that of transverse bars, or irregular markings. The most perfect kind of

vascular structure is shown in the *spiral vessel*, which consists of a tube with a conical termination at each extremity, traversed by a filament regularly coiled from one point to the other (Fig. 12.) This filament is usually single, but sometimes double, or even triple; and in the very large spiral vessels of the *Nepenthes* (Chinese pitcher-plant) it is quadruple (Fig. 13.) The tubes in their perfect state contain air only; they are found in the delicate membrane surrounding the pith of Exogens, and in the midst of the woody bundles occurring in the stem of Endogens; from thence they proceed to the leaf-stalks, through which they are distributed to the leaves. By careful dissection under the microscope, they may be separated entire; but their structure may be more easily displayed by cutting *round*, but not *through* the leaf-stalk of the strawberry, geranium, &c., and then drawing the parts asunder. The membrane composing the tubes of the vessels will thus be broken across; but the fibres within, being elastic, will be drawn out and unrolled, as seen in Fig. 14. A very curious analogy to this structure is exhibited in the *tracheæ*, or air-tubes of insects, which ramify by minute subdivisions through the whole of their bodies. These tubes are formed, like the spiral vessels of plants, of an external membrane distended by spiral fibre, which is coiled with the most beautiful regularity (Fig. 19); the principal difference in these two structures being that the air-tubes of plants, are closed vessels, and that their gaseous contents find their way through the delicate membrane which composes them, by the capability of permeation, which will be subsequently described; while the tracheal system of insects exhibits the most beautiful and minute ramifications, formed by the subdivision of its principal trunks, which communicate directly with the atmosphere.

27. There are some peculiar modifications of the regular type of the vascular structure of plants, which deserve notice, not only on account of their intrinsic importance, but also as exhibiting analogies still more remarkable in the structure of the respiratory organs of the animal and vegetable kingdoms. The tubular vessels occurring in many parts of the stem, roots, and leaf-stalks of flowering plants and ferns, and exhibiting traces, more or less distinct, of a spiral structure, are called *Ducts*. Of these, some approach so nearly to the character of a spiral vessel, that they could scarcely be distinguished from it; the difference between them being confined to the absence of elasticity in the spiral fibre, which prevents it from being unrolled, as in the former case, without snapping. Another form is that in which the spiral fibre is not continuous, but is broken into rings; whence the vessel is called an *annular* duct. The rings in some vessels are very close, in others at considerable intervals; but if the vessel be traced to any extent, some indications of a spiral fibre may generally, if not always, be found (Fig. 15). It appears probable, since vessels are found in all states

of transition from perfectly spiral to annular, that the original tendency was to develope a spiral fibre; but that the vessel during its formation was elongated more rapidly than the fibre, from its want of elasticity, could keep pace with, and that the latter was consequently broken into rings. A structure, exactly corresponding, is met with in the *trachea* (windpipe) of air-breathing vertebrata. This is composed of cartilaginous rings, usually separate from one another, but united by a membrane; thus resembling an annular duct. In some birds, however, traces of a spiral arrangement of the cartilage are met with; and this appears to be the regular structure of the trachea in the *Dugong* (one of the whale tribe), where we see a continuous strip of cartilage disposed in a spiral form, and occupying the place of several rings, but occasionally terminating in the usual manner (Fig. 20).

28. Another modification of vascular structure is shown in Fig. 16. It is produced by the partial adhesion of the coils of a close spire to one another, and to their enveloping membrane, so that the fibre itself is no longer distinguished, but irregular dots or spaces are left in its interstices. This is also peculiarly interesting from the analogue it meets with in the animal kingdom. The tracheæ of insects occasionally exhibit dilatations in their course into air-sacs (Fig. 21); the walls of which, in some instances, appear simply membranous; but in other cases exhibit a distinct continuation of the spiral structure of the tubes. Most frequently, however, the membrane has the aspect represented in Fig. 22, which seems due to the same partial adhesion of the fibres as has been traced in the vegetable strueture.

29. Two other forms of vascular tissue, the *reticulated* and *dotted* ducts, are represented in Figs. 17 and 18. They appear to take their origin in a spiral structure, modified by the irregular fracture of the fibre, and the subsequent adhesion of its fragments. Thus, in the reticulated duct (Fig. 17), the spire may be oceasionally traced, although the general disposition of the fibre is in an irregular network, with large interspaces. These spaces are often observed to be more contracted and definite; and thus a transition is indicated to the charaeter of the dotted duct (Fig. 18), of which the dots appear to be the intervals not covered by the expansion and adhesion of the fragments of the fibre, just as in the separate cell (§ 23). It seems, therefore, that the dotted duct may be formed, either by the junction of distinet cells (of which some evidence remains in the imperfect partitions), or upon the type of a spiral vessel, when the tube will be more continuous. The mode in which the dotted structure is acquired, is evidently the same in both eases.* The animal kingdom presents an instance of similar degeneration from the original type, in the

* This view of the structure of *dotted ducts*, which is the one taken by Mr. Slack, manifestly tends to reconcile the conflicting accounts which have been given of their origin;

bronchial ramifications of the trachea, in which the irregular patches of cartilage (Fig. 23) exhibit an appearance exactly conformable with that which has just been described.

30. The description which has been now given of the vegetable tissues, will suffice to show the mode in which they are mutually connected, as well as the forms which are characteristic of each kind. Many varieties have been passed by, as not of particular interest in regard to the present object, although in a full description of the Anatomy of Plants they would receive more especial notice. It is scarcely possibly to observe the different forms which result from the varied combinations of the simple elements of *membrane* and *fibre*, each of them probably having its peculiar function in the vegetable economy, without being struck with the simplicity of the plan by which creative design has effected so many marvels, as well as with the extreme beauty and regularity of the structures which are thus produced. The comparison of such specimens of Nature's workmanship as the meanest plant affords, with the most elaborate results of human skill and ingenuity, serve only to put to shame the boasted superiority of man; for whilst every additional amplification of the latter, by the increased powers of our microscopes, serves but to exaggerate their defects, and display new imperfections, the application of such to organized tissues, has only the effect of disclosing new beauties, and bringing to light the concealed intricacies of their structure. If such be the result of the study of the minute anatomy of vegetables, that of animals should still more impress our minds with astonishment and delight, from the increased variety of the forms which the same simple elements are capable of presenting, and the extraordinary complication of these (frequently so great as to baffle the most skilful enquirer), which becomes necessary for the production of the phenomena of animal life, themselves so varied and so conplex.

IV.—*Elementary Structure of Animals.*

31. The great bulk of the fabric of animals is made up of tissues composed of the same elements as those which constitute the whole of the vegetable organism, namely, *membrane* and *fibre*; and, in fact, it may be regarded as composed of fibres alone, since the most delicate membranes (as will presently be shown) are formed out of this arrangement of organised particles. Two other elementary forms of structure are found in animals, which have no analogy with anything

many Physiologists referring them to the vascular system, whilst others, with much reason, maintain that they have originated from vesicles of cellular tissue. The spiral vessel is manifestly only an elongated spiral cell, from the type of which the dotted cells and dotted ducts may arise on one side, or the spiral vessel and reticulated ducts on the other; and every grade of transition may be detected in the same plant between these different forms.

that exists in plants; these are the *muscular* fibre, and the *nervous* matter. It is very interesting to remark, however, that these are, for the most part, restricted to the parts of the fabric which are subservient to the functions purely *animal*, namely, sensation and voluntary motion; and that wherever they are introduced into the apparatus of *organic* life (CHAP. IV.) it is for the purpose of adapting it to the conditions of animal existence. Thus, we shall find (§ 237) that one of the characteristics of animals is the possession of a digestive cavity, in which the food is stored up for the continued supply of the absorbent system, and in which it undergoes a certain degree of preparation; this addition to the absorbent apparatus of plants being required by the locomotive propensities of animals, and also by the nature of their food. Now, for the introduction of aliment into this cavity, for the expulsion of the excrementitious matter from it, and (where the cavity is prolonged into a tube, as in the higher animals,) for the motion of its contents from one extremity to the other, an apparatus of nerves and muscles becomes necessary; but still this cannot be regarded as an essential part of the absorbent system, which is composed, as in plants, of the simple elements, membrane and fibre. A similar explanation might be given of the introduction of muscular fibre into the circulating apparatus of animals; since the regularity and constancy of the movement of the blood which is required in them, rendered necessary the addition of a central impelling organ (CHAP. VI.) which could only be constructed of a tissue possessed of the peculiar contractile powers of muscular fibre. It is not a little curious, moreover, that there should be a perceptible and essential difference in the muscular tissue employed in the vital organs, and in the locomotive apparatus (§ 43).

32. The *fibres*, by the union and interlacement of which, the greater part of the animal tissues appear to be composed, are of extreme minuteness, and require a very high magnifying power to recognise them. Those which are perceptible to the naked eye, as the white glistening threads traversing fibrous membranes, are composed of many elementary fibres united together. Probably those of which the cellular tissue is formed are among the most minute; and these are said to vary from $\frac{1}{3230}$ to $\frac{1}{1430}$ of a line in diameter. They are transparent and have edges quite smooth; and they appear principally composed of gelatine. These fibres may unite in bundles to form larger fibres; or they may be arranged side by side into the delicate membranous plates or *lamellæ*, of which all membranous expansions appear formed. Many microscopic observers have maintained that these ultimate fibres are themselves made up of globules arranged end to end; but the appearance which has led to this belief may be regarded, almost with certainty, as an optical illusion, proceeding in part from imperfection in the instrument employed, and in part from the preparation which the object has undergone. The ultimate

fibres are distinctly visible in the membranous lamellæ which by their interlacement form cellular tissue; and also in the delicate membrane which forms the vesicles of fat. Some physiologists maintain that these fibres are tubular, and serve for the conveyance of the serous part of the blood; but this can scarcely be granted, when we consider their condensed arrangement in various membranes and other structures, which exhibit a regular gradation from the superficial fascia, into which the cellular tissue passes almost imperceptibly, to the dense tendons in which so little circulation of fluid takes place.

33. The most regular and definite form of *cellular tissue* is that in which fatty matter is deposited, and which has therefore been denominated *adipose* tissue. This seems to be exactly parallel with the simple membranous tissue of plants (§ 23); consisting, like it, of isolated vesicles formed of a delicate transparent membrane. And, as in certain parts of the vegetable organism, we find the cavities filled with oil or gummy matter stored up in them for the future nutrition of growing parts, so does it appear that the substance which composes the fat of animals (a mixture of oil and stearine), is separated from the circulating fluid and deposited in these vesicles for a partly similar purpose. That the vesicles do not communicate with one another, is proved not only by microscopic examination, but by the fact that their contents, which are fluid in the living body, have no tendency to gravitate. They are clustered together in masses, each of which is enclosed within a distinct membrane, on which blood-vessels ramify; these masses are again clustered together into larger ones under another envelope; so that any mass of fat may be separated into a number of distinct nodules, which may be several times subdivided into others before the ultimate vesicles are arrived at. The diameter of these is stated by Raspail at from about $\frac{1}{1000}$ to $\frac{1}{200}$ of an inch; they are much smaller in the young animal than in the adult. Perhaps of all the animal tissues, this is the one which most resembles those of vegetables; and it is curious that it does so not only in structure but in chemical composition. The gelatine of which the membrane is principally composed, may be regarded as the least *animalised* of the proximate principles which enter largely into the organism, containing a smaller proportion of nitrogen than albumen, and much less than fibrin; whilst both of the ingredients which constitute the fatty matter itself, are composed of oxygen, hydrogen, and carbon alone, being very analogous in the proportion of those elements to the fixed oils produced by vegetables.

34. The structure which is ordinarily termed *cellular tissue* in the animal body, differs so much from that just described, as well as from that of plants, that it would perhaps be better if some different appellation were given to it. It consists of a net-work of fibres and membranous lamellæ, woven into a minutely reticulated texture; and a number of

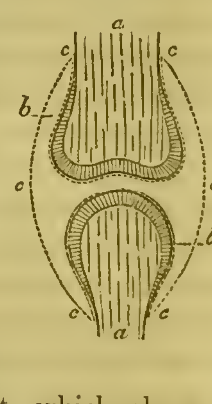
little cells or cavities are thus formed, which contain a watery fluid slightly impregnated with albumen, and very similar to the serum of the blood. These cavities are not, however, surrounded with a distinct envelope, cutting them off from one another; but, being merely separated by the net-work of fibres and strips of membrane which forms the solid part of the texture, they communicate freely with each other, and fluid or air injected into one part is speedily transmitted into the neighbouring portions of the structure. There is great difficulty, therefore, in submitting this tissue to a satisfactory examination, since its condition after death and when removed from the body is necessarily very different from the state in which it exists in the living structure, the fluid which should distend its cavities having escaped. Some physiologists have regarded it as possessed of a very low degree of organisation, and as resulting merely from the disengagement of gaseous particles in the midst of coagulating lymph; whilst others have gone to the opposite extreme, and considered it as entirely composed of blood-vessels, nerves, and absorbents. Of its importance in the animal economy there can be no doubt; but it will be found that it rather contributes to the performance of the special functions of the different organs which are formed, as it were, upon the basis of it, than executes any definite vital actions itself. As among plants, we find that the simplest form of tissue is that which constitutes in animals the entire bulk of the least organised species, and enters most largely into the fabric of the highest; and it is very interesting to remark that the more nearly we approach the confines where these two kingdoms border upon one another, the more closely does their elementary structure approximate. For among the Porifera (§ 121), the body, or at least the soft portion which clothes the skeleton, consists of a number of translucent globules which are not perceptibly joined together, and thus resembles that loosely aggregated gelatinous tissue which constitutes some of the lowest plants. Even in the more complex Polypifera (§ 119) and Acalephæ (§ 108), all that is evident of their organisation is a soft and gelatinous matter, analogous to the pulpy substance of fruits, consisting of vesicles loaded with fluid. A similar gradation in the characters of cellular tissue may be observed in watching the development of any of the higher animals; thus, the *germinal membrane*, from the folds and layers of which most of the organs of the embryo are developed (CHAP. XIII.), is first perceived within the egg to consist of an aggregation of globular corpuscules; and at a later period the whole mass of the embryo presents a structure very analogous to that of the inferior animals just described. The tissues peculiar to different organs are developed within this; and it may be observed, either in ascending the animal scale, or in watching the gradual evolution of any one organism, that in proportion as these are formed, the cellular tissue becomes less predominant in the fabric, and performs a less important part in its

functions. This is exactly parallel to what occurs in the vegetable kingdom; for whilst the lowest classes are entirely composed of cellular tissue, which serves every purpose in the economy, in ascending to the higher ones we encounter new tissues, adapted for special functions, which supersede it as regards these objects. The same is the case in the development of the embryo, which at first consists of a soft gelatinous mass, and afterwards presents in succession the forms of cellular structure, woody fibre, and vascular tissue.

35. Cellular tissue is diffused through the whole fabric of the adult animal, and enters into the composition of every organ; so that it has been said, that if all the particles of other kinds of structure, and all the deposits in its interstices, could be removed, there would still be left a kind of framework in which the form and arrangement of every portion of the body would be perceptible. Hence results its uninterrupted continuity through the whole body; since it not only fills up the spaces left between the different organs, connecting them together more or less closely, according to degree of mobility which is to be permitted them, but binds together their minutest portions. Thus, the ultimate nervous filaments, and the minutest muscular fibres, are united into bundles by tissue of this character; these bundles, again, are incorporated into larger ones by another investment of the same kind; and even the trunks of the nerves and the bodies of the muscles possess similar sheaths. In the healthy condition of this tissue, its interstices are filled with fluid, secreted from the blood vessels; and it appears to be upon the due relation between the distention of the cavities, and the elasticity of the fibres (both of which states are liable to be affected by diseased conditions of the nutrient actions), that its peculiar *tone* in the living body depends. This property is manifested in the resiliency of the skin, after it has been pressed and the pressure has been removed; here the fluid contained in the cavities beneath, is at first expelled into the neighbouring interstices, and the elasticity of the fibres by which these are bounded forces it back again as soon as the compression is taken off. Again, the retraction of the sides of a wound made in the skin and subjacent tissue during life, is due to the same property, and may be explained on the same principle. But when the tissue of any part becomes over-distended with fluid, as in local dropsies, either from an increase in the amount of secretion, or from inactivity of the absorbent process which ought to keep it in check, the fibre loses its elasticity; and the surface, in consequence, *pits* on pressure, not immediately recovering itself when the obstacle preventing the return of the fluid to its usual situation is removed. It is not improbable, however, that in many cases the loss of elasticity is the result of diseased nutrition; and that the accumulation of fluid, instead of being its cause, is its consequence. A curious fact may be noticed regarding the chemical composition of cellular tissue

at different periods of life, which is analogous to what has already been mentioned of its variations in structure. In the early period of development, it consists almost entirely of gelatine, and hence it is that the flesh of young animals affords much more jelly by boiling, than that of adults. But in the advance of life, a deposition of albumen, a more highly animalised principle, replaces a part of it; so that even in the chemical composition of this primary tissue, it is only progressively that the characters of the perfect animal are evolved.

36. The primitive fibres of which cellular tissue is composed, sometimes arrange themselves into distinct membranes, which present a uniform surface, and have none of these interstitial cavities which have just been described. Of these, the one that presents the nearest approach to the characters of cellular texture, is the *serous membrane*, which, indeed, differs but little from the thin and expanded plates of that tissue which are frequently met with as envelopes to different organs. It appears to be formed of fibres aggregated into bundles, which are closely interwoven together, so as to leave no appreciable interstices; and it is characterised by the peculiar smoothness and glistening appearance of its surface. This tissue is confined to particular parts of the body; and it is remarkable that wherever it occurs, it forms a closed bag or sac.* The simplest form of such sacs is presented by the *bursæ* (purses) as they are termed, which lie beneath or around tendons, and sometimes are interposed between them and the skin; these are frequently round, in other instances of an irregular shape, and contain a serous fluid which is secreted from their internal parietes; and their object appears to be to protect the tendons and to facilitate and direct their motion. The arrangement of the *synovial membranes*, as they are termed, is more complex, and will serve to illustrate that of other serous membranes, which is less readily explained. These membranes form an important part of all the joints or articulations, investing the cartilages which cover the adjoining ends of the bones, and affording them a surface of exquisite smoothness and evenness, by which they may play readily upon one another. The mode in which this is accomplished, and yet the closure of the sac maintained, may be understood by the accompanying ideal section of a joint, which shows the extremity of a bone, and of that which is articulated with it, *a*, *a*, covered with a layer of cartilage *b*, *b*; and over this, the synovial membrane (marked by the dotted line) which envelopes the ends of the bones, and is then reflected back from one to the other, *c*, *c*. It is



* To this general law, there are one or two comparatively unimportant exceptions.

so closely united to the cartilage, that some anatomists deny its presence on its surface; and this has indeed been rather inferred from analogy, than actually proved. In some of the joints, as that of the knee, there is a complicated apparatus of ligaments which appears to be *within* the synovial capsule; but they are in reality on its exterior, each being surrounded by a sheath of membrane which is prolonged from the walls of the sac. Into the cavity of the sac is secreted a fluid termed *synovia*, which by its lubricity prevents friction; it has an oily appearance, but consists, like the fluid of the bursæ, of water holding alkaline matter and albumen in solution, and thus differs but little from concentrated serum (§ 365). What are more commonly known as *serous membranes* line the three great cavities of the body, those of the head, chest, and abdomen; enveloping the viscera which they contain, in such a manner as to afford them an external coat (as the synovial membrane does to the articular cartilage); and being also reflected over the interior of the cavity with which they are in contact (as the synovial membrane over the opposite articular surface), so as to form a shut sac, intervening between the walls of each cavity and its contents, and thus to facilitate their movements, by forming a smooth surface by which each may glide over the other. This is evidently of peculiar importance where such constantly-moving organs as the heart and lungs are concerned. In the healthy state it seems probable that the opposite surfaces of the serous sac are in absolute contact, (that which covers the lung, for instance, touching that which lines the chest); and that the secretion from each, which seems almost identical with the serum of the blood, is sufficient only to keep it moist and smooth; but in diseased conditions this may be excessive, and may accumulate to an injurious extent. Although serous membranes do not appear in general to possess a high degree of vitality, they are capable of taking on a state of violent inflammation, in which the fibrinous part of the blood is exuded upon their surface; this may be organised into new membranes, and produce injurious adhesion between the opposite sides of the sac. The membrane which lines the heart and blood vessels presents many of the characters of this tissue.

37. The next elementary form of animal structure to be considered, is that which is denominated *fibrous membrane;* this composes a great variety of organs, but must not be confounded with the muscular and nervous structures which are also fibrous, being only another modification of the same elements that compose cellular tissue. There are two kinds of fibrous tissue, the white and yellow. Of the white are constructed tendons and ligaments, as well as the fibrous membranes which cover the bones and other organs. These are characterised by the presence of white or greyish fibres, sufficiently large to be seen by the naked eye, possessed of considerable density, and united by membrane of a looser character. They appear to consist of bundles of primitive fibres,

containing a large proportion of albumen, and very much condensed; sometimes they run simply parallel to each other, especially when they form membranous expansions like the *fasciæ* of muscles; whilst, in other instances, they interlace most minutely with one another, as in the *dura mater* and most tendons, so as not to be unravelled except by very prolonged maceration. The gradual transformation of common cellular tissue into fibrous membrane, may be frequently observed; and there would seem to be no essential difference between their constituent parts. And between the various forms of fibrous tissue there is a closer resemblance than would be at first suspected; for a tendon differs from a ligament in little else than the greater condensation of its fibres, (of the arrangement of which a microscopic view is given in Fig. 24), and the smaller proportion of soft tissue intervening between them. Fibrous membranes appear to possess but a low degree of vitality, the circulation through them being inactive; and the offices which they perform in the economy are almost purely mechanical. They possess but little elasticity beyond that conferred by the small quantity of interfibrous cellular tissue; but their great characteristic is their toughness, by which they are enabled to resist forces which would otherwise tear or rupture them. Hence they are peculiarly adapted to enclose delicate organs like the brain; to connect separate parts so as to preserve their mobility, as in the joints; or to sustain a powerful strain, as where the muscles terminate in tendons. The yellow fibrous tissue possesses much more elasticity than the white, and is employed in such situations as peculiarly require the exercise of this property. Thus, it composes the ligaments by which the vertebræ (or bones of the spine) are held together; and, in cattle, the strong elastic cord which stays the head, is formed of the same. It also unites the valves of Mollusca (§ 102) in such a manner as to keep them a little apart, unless its elasticity is counteracted by the exercise of muscular power; and, by a similar contrivance, the claws of the Feline tribe are kept retracted within their sheath, except when voluntarily protruded by muscular action. The fibres which characterise the structure of these ligaments, seem to be of a different nature from those just described, and to be in fact *sui generis*, presenting an obvious relation in their peculiar contractility to muscular fibre, between which and cellular tissue they may be regarded as intermediate. Their disposition is seen at Fig. 25.

38. A very important modification of cellular tissue, or, at least, of its elementary constituents, is the texture denominated, from its peculiar secretion, *mucous membrane*. This, like serous membrane, appears formed by the close interlacement of fibres; but the surface, instead of being smooth and glistening, is soft and unpolished, like the pile of velvet, or the rind of a ripe peach. Nor is it by any means uniform; for there are a number of little depressions or pits into which it

descends; and from the lining which it gives to these, the secretion of mucus appears to be principally formed. Unlike serous membranes, those we are now considering line the *open* cavities of the body; thus, one commences at the mouth (being there continuous with the skin), communicates with that which lines the nostrils and covers the spongy bones (upon which the olfactory nerve is minutely distributed), and then divides into two branches; one of these passes down the air-passages, and is continuous over the whole interior of the lungs; the other lines the alimentary tube through its whole extent, communicating again with the skin at its farther extremity, and sending prolongations along the ducts of the glands which pour their secretions into it,—these prolongations ramifying and subdividing in such a manner as to be, in fact, the essential constituents of the glands themselves (CHAP. XI). Another mucous membrane covers the eye, and lines the eyelids, sending a prolongation which forms the lachrymal gland, and another which lines the lachrymal duct and thus communicates with the membrane of the nose. Another lines the urinary passages, and forms the tubuli of the kidney (§ 465); and another has a similar connection with the tubes and cavities of the generative system. All these, it is obvious, are continuous with the skin at some point or other; and anatomical examination of the cutaneous tissue shows that it is not itself organically different from the mucous membrane, consisting, like it, of simple fibres interwoven together in all directions, and having almost identically the same chemical composition,—gelatine predominating in both. Although in the higher animals the very different functions which the external and internal portions of this membrane (for so they may be regarded) have to perform, are so different as to lead to such modifications in their structure as render them incapable of altogether fulfilling each other's offices, they would seem, in some of the lowest, to be mutually convertible; the lining of the stomach in the common green Polype (§ 115) being capable of becoming the skin by inversion, and what was previously the skin serving equally as well as the other to line the digestive cavity. In the higher classes, the skin is the principal organ of common sensibility, the nerves of touch being minutely distributed upon it; and it also furnishes the means for dissipating a large proportion of the superfluous fluid of the system by exhalation. On the other hand, the mucous membrane lining the alimentary canal is specially modified for absorption; that of the lungs, for the interchange of gaseous ingredients between the blood and the air; that of the various glands, for the separation or elaboration of their products from the blood,—and so on.

39. Mucous membranes are very highly organised, being copiously supplied with blood vessels, nerves, and absorbents; the nerves predominating in the skin, and on the membranes lining the nose and mouth; the blood vessels on the pulmonary and other secreting mem-

branes; and the absorbents on that of the intestinal canal. The secretion of mucus which constantly covers them, appears to protect them from the contact of acrid or irritating substances; and it is often observed that if this secretion be from any cause insufficient in quantity, the membrane becomes inflamed. It usually seems to proceed from the general surface, as well as from the little pits or follicles into which that surface is prolonged; but when another secretion takes place from the surface, as that of the epidermis from the skin, or of the epithelium from the membrane of the œsophagus and stomach, this is probably restricted to the mucous crypts just mentioned. The skin of fishes is so largely furnished with these crypts, as almost to present the characters of a mucous membrane; since the protection afforded by their secretion seems necessary for the defence of the body from the contact of the irritating saline fluid in which it is constantly immersed. The *epidermis* or scarf-skin, is formed by a secretion from the surface of the true skin, presenting itself in man in the form of little scales or plates, of which the outer ones are constantly being thrown off, while new ones are being formed in the interior; these have at first somewhat the appearance of cells or vesicles, but subsequently become dry and flat. The *epithelium*, which covers the mucous membrane of the mouth, and extends down the œsophagus into the stomach, as well as that which covers the conjunctiva of the eye, has a very similar structure, and appears to be only a form of mucus which is capable of becoming solid, similar scales being observed occasionally diffused through the mucus of the lower part of the intestinal canal, where no epithelium is formed. Various other substances are formed from the skin in the same manner with the epidermis, and are therefore termed epidermic appendages. Of this kind are the nails, claws, hoofs, scales, &c. which consist of a hardened exudation from the surface, and which all have a laminated structure. Not very dissimilar in character are the hair, spines, quills, feathers, &c. found on other parts, which are secreted by follicles or bags contained in the substance of the skin, and opening on its surface; these follicles differ but little, except in degree of development, from those which elsewhere secrete mucus. All these parts are extra-vascular, that is to say, not permeated by nutrient blood vessels or absorbents; and they consequently undergo no change when once formed.* It will be hereafter seen that these extra-vascular secretions have a much more important office in the lower animals, con-

* Though this is the general fact, yet there are some exceptions which it is not easy to explain. Thus, many instances are on record of the colour of the hair being suddenly changed, usually through some mental emotion. This may, perhaps, be produced by a new secretion from the hair-follicle, of some agent which is conveyed along the tube of the hair, as along any other inorganised canal, and acts chemically upon its substance. In the same manner, also, may be produced that periodical change of colour in the plumage of many birds, which ornithologists have noticed, and which is independent of change in the feathers themselves.

stituting their entire skeletons; and that the horny casing of Insects, the massive shells of the Mollusca, the lighter calcareous tegument of the Crustacea, and the stony axes of the Polypifera, are all to be regarded in the same light as the epidermic appendages of the Vertebrata (§ 82).

40. It has been seen that the mucous membranes are the parts of the fabric most concerned in the performance of the *organic* functions; their especial office being to maintain the communication between the nutrient system and the external world, by obtaining from the latter the materials requisite for the supply of the body, and by returning to it the superfluous or injurious portions. The constant activity of the processes in which they are concerned, keeps them in intimate dependence upon the due supply of blood which is the stimulus to their actions; and accordingly we find that the circulation through them is more energetic, and more liable to be affected by temporary changes in their condition, than that of probably any other organ except the brain. Thus, the colour presented by the mucous membrane which lines the stomach, depending entirely on the degree of fullness of its minute vessels, is completely changed by the stimulus of food, which excites the secretion of gastric juice, and, consequently, the flow of blood into its capillaries; so that the pale hue which the surface presents, when the process of digestion is not going on, rapidly changes to a rosy tint on its commencement. The hue of the skin, in like manner, is affected by alteration of temperature, mental emotions, &c.; and it is an obvious consequence of this susceptibility of change, that these parts are peculiarly liable to the attacks of disease, since they are so much exposed to the influence of external agents.—At the opposite extreme, in point of intricacy of organisation, and activity of function, is the *cartilaginous* structure, which assists in the support and protection of the vital organs. This, in many animals, forms the entire skeleton; and in the early state of the human body it serves the same purpose. Even in adults, it exists in many parts where a certain degree of flexibility and elasticity are to be combined with toughness and density; and we consequently find it covering the articular surfaces of bones, as well as giving the form and substance to the eyelids, ears, and other similar parts. In its simplest state, cartilage can hardly be said to exhibit any trace of structure, being apparently homogeneous throughout. By prolonged maceration or boiling, however, something like filaments of cellular membrane may be detected in it; and as it may be easily shown to contain both gelatine and solid albumen, it may perhaps be regarded as formed by the deposition of the latter material in the cavities of cellular tissue. Many of the cartilages, however, exhibit an evident fibrous structure; and here the albuminous part may in them be regarded as organised in the same manner as that which composes the white glistening lines on fibrous membranes (§ 37). Sometimes the fibrous structure prevails to so great an extent, as to give

an almost indeterminate character to the tissue; this is the case, for instance, in the intervertebral substance which lies between the bones of the spinal column. The exterior of each mass appears composed of fibrous tissue, the interstices between which are filled up with cartilage; but the fibres gradually diminish in the interior laminæ, and the cartilaginous matter becomes less dense; so that in higher animals the tissue is comparatively soft, and in fishes the centre is occupied with a sac containing fluid. The cartilages which precede, in the fœtus, the portions of the skeleton which are to be subsequently osseous, do not exactly correspond in the ultimate arrangement of their particles, with those which are permanently to retain their soft condition. However, in general character they are obviously the same; and their sections, before the process of ossification has commenced, exhibit an almost homogeneous substance, with little trace of defined structure. At this period, it is doubted by many whether they possess blood-vessels of sufficient size to convey the red particles, as they are altogether destitute of colour; and the same doubt is entertained as to the permanent cartilages, which seem to be the parts of the fabric in which vitality is feeblest. Their elasticity prevents them from the liability to be as severely affected by mechanical violence as bones are; and therefore they do not require the same power of reparation. All their actions are of a physical character simply; and need only a structure endowed with the physical property of density combined with some degree of flexibility and elasticity. It is during the process of ossification that the greatest activity is exhibited in this tissue, red vessels rapidly extending through it, and effecting an important change in its character. This change appears to consist essentially, in the removal of a portion of the albumen, which previously filled up the interstices of the cellular tissue, and its replacement by particles of calcareous matter deposited by the blood, so as to convert the cartilaginous into the osseous structure now to be described.

41. The essential characteristic of the *osseous* or *bony* tissue, is its possession of a large quantity of calcareous matter, deposited in the interstices of an organised structure, in which exists an apparatus of vessels, &c. capable of performing vital changes with considerable activity. In this consists its difference from the extravascular structures of which the skeletons of the invertebrated animals are composed; since the latter are not susceptible of being modified by any agents except those which act upon their surface (§ 100), whilst the former are as capable as any part of the organism to which they belong, of undergoing the processes of interstitial absorption and deposition (§ 232). The particles of calcareous matter cannot themselves be regarded as organised, since they retain, if not their crystalline form, at least their crystalline arrangement; but they are strictly analogous with those which are deposited, in smaller proportion indeed, in the tissues of vegetables. These particles consist of

the carbonate and phosphate of lime, both of which are present in variable proportion, (the latter usually predominating considerably), in all bones, and even in minute quantity in cartilage; they certainly exist there as salts, and not in chemical combination with organic principles. The texture of bone is usually fibrous; but the fibres are frequently united into lamellæ or plates, which sometimes form regular layers, and sometimes bound *cancelli* or cells. In the long bones, we find in higher animals a central canal, which in Birds is hollow, and in Mammalia is filled with a fatty substance termed marrow. This canal is surrounded by very compact bony tissue, in which the laminated structure is most distinct; whilst towards the extremities, the compact laminæ become thinner, and the interior becomes filled with cancellated structure, analogous to that which intervenes between the hard external plates of the flat bones. In Reptiles and Fishes, however, there is not this distinction of parts, the bones being solid throughout, but nowhere presenting the same firmness as that of the exterior of the bones of Birds and Mammalia, their texture being of a spongy character. Whatever may be the arrangement of the constituent parts of bones, however, there can be little doubt that their texture is ultimately reducible to a form of cellular tissue, in which cartilaginous and calcareous depositions have taken place. The latter may be removed by the action of acids; and a flexible elastic substance is then left, possessing the characters of soft cartilage, but exhibiting marks of higher organisation. A very complicated apparatus of minute canals is observed in it,* which probably mark the situation of the calcareous

* For the latest details on the minute structure of bone and cartilage, see Müller's Physiology, vol. I., p. 377, &c. These tubes (termed Haversian, from the name of their discoverer,) contain medullary matter; and, indeed, the central canal, as well as the separate cells, may be regarded as enlargements of them. Around each canal is observed a deposition of bony matter in concentric circles; and on each circle are radial lines, which seem to divide it into narrow tubes pointing from the centre to the circumference. The teeth have been imagined by many to be extravascular structures (§ 39), or mere secretions, formed in successive laminæ like hair or quills; or to be, at least, only connected with the circulating and absorbent system through the membrane which lines their cavity. The recent enquiries of Müller, Purkinje, Retzius, and Mr. Owen, however, (the last of whom communicated the results of his observations to the British Association, at its Newcastle meeting,) have shown that their substance is composed of tubular fibres, which are generally arranged in a radiating manner from the centre to the circumference, so as to be perpendicular to their surface, and formed of animal membrane containing a deposition of calcareous matter. These tubes frequently ramify and inosculate with great minuteness, and communicate with cells, in which also calcareous matter seems deposited on a basis of membrane. In the teeth of higher animals, there are no large branches connected with the central pulp-cavity; so that the structure resembles that which a bone would present, if destitute of Haversian canals, but retaining the medullary cavity. But among fishes and other inferior species, there are seen coarse tubular ramifications of the pulp-cavity, containing a sanguineous medulla, which are continuous with those of the bone to which the tooth is attached; and here, therefore, the resemblance to bone is much closer. This is one of the many instances of a *special* structure, for a *special* function, not being superadded to, but *elaborated from* one more *general*, in proportion as we ascend the scale (§ 200).

deposit; but what connection these have with the blood-vessels which permeate the structure does not seem distinctly ascertained. If, on the other hand, the animal portion be removed, either by heat or chemical agents, a brittle mass remains, which preserves its original form, and exhibits the particles of calcareous matter in a state of loose aggregation. By long-continued boiling, the organised part may be dissolved in water, and then possesses the characters of gelatine, of which principle it seems to be mostly composed; it probably also contains some albumen, though this ingredient exists in much less proportion than in cartilage, and seems to have given place to the calcareous matter. The proportion of the animal to the mineral matter, however, varies in different species; always bearing a relation to the age of the individual. Young bones possess considerable elasticity, but are deficient in density, assimilating more in their properties to cartilage; whilst those of old persons are so much consolidated by the continual deposition of mineral matter, that they become extremely hard and brittle.

42. All the tissues now described are formed, more or less evidently, upon the basis of cellular structure. It would be easy to multiply the number of elementary parts, by describing as distinct fabries what are only modifications of others, or combinations with one another. But those which have been specified will probably be found to comprehend all the essentially different varieties which are met with in the animal kingdom, with the exception of the two which are quite peculiar to it,—the muscular and nervous tissues. And these are rather peculiar in vital properties and chemical constitution, than in their form of organisation. Observation of *muscular* structure shows that it possesses a fibrous texture; and when any muscle is particularly examined, it is found to be separable into a number of distinct *fasciculi*, or bundles of fibres, which are connected by cellular tissue. These again are divisible into smaller fasciculi, which are similarly united; and each of these, if carefully analysed, is found to consist of a number of distinct fibres, which possess a very peculiar and characteristic structure, and are usually spoken of as the *ultimate fibres* of muscular tissue. (This statement applies, however, only to the muscles of voluntary motion; for it will presently be seen that the structure of the muscles connected with the organic functions is very different.) These fibres are usually about $\frac{1}{400}$ of an inch in diameter, varying in different organs and in different animals from about $\frac{1}{250}$ to $\frac{1}{700}$. Each appears to possess a tubular structure, and to be formed of a number of smaller filaments arranged longitudinally, bound together by transverse or circular bands. According to the late observations of Mr. Skey,* each of these filaments, of which about 90 or 100 unite to form one tubular fibre, has itself a tubular structure; but this is a point not

* Philosophical Transactions, 1837.

easily determined, from the extreme minuteness of the filament, which is only about $\frac{1}{10000}$ part of an inch in diameter. That they are bound together by transverse rings is inferred by Mr. Skey, not only from the striated appearance of the fibre itself (Fig. 26), but from the fact that each separate filament exhibits indentations at distances corresponding with those of the striæ on the perfect fibre. The tubes of the fibres are found to contain a glutinous fluid, but its nature has not been distinctly ascertained; by Dr. Quain it is stated that distinct globules are discernible in it. This may be reasonably doubted until these globules shall have been shown *out of* the tube; since the combination of the transverse striæ with the markings of the longitudinal filaments is very liable, where the tube itself is viewed, to occasion an appearance resembling globular structure, the true nature of which cannot be detected except by a very superior microscope. This has been the source of error among those who imagined that the muscular fibre itself is made up of globules; and some have even maintained that these globules are the red particles of the blood, without sufficiently attending to the disproportion in their size.

43. The muscles of organic life present a very different appearance. Their fasciculi are not so distinct; and when the attempt is made to separate them into fibres united by cellular tissue, it is found that they do not possess this structure, but that the minute filaments are interlaced into an irregular net-work (Fig. 27), in which nothing analogous to the *fibre* of the muscles of voluntary motion can be detected. This, at least, is the character of the muscular structure of the alimentary canal, from the point where the œsophagus enters the thorax; above this, the œsophageal fibres, as well as the constrictors of the pharynx, present the appearance first described. In the heart, a kind of mixed structure is seen; a tendency to the formation of tubular fibres, in the midst of the irregularly reticulated mass of filaments, being discernible. The nature of the actions of these parts seems closely connected with the arrangement of their elements. In the muscles of voluntary motion, the object is to approximate by their contraction two distinct points, upon which, therefore, all their force is concentrated; and the filaments, in which the contractile power resides, are arranged in the most advantageous manner to effect this purpose, being parallel to each other, and closely united so as to harmonise in their actions. In the muscles of organic life, on the other hand, a rapid and energetic contraction in a single direction is not what is required; but a slower movement propagating itself gradually over an extended surface, and operating in several different directions. In the heart also, the intermediate condition of the structure appears related to that of the function; for energetic and decisive contractions are here required, but these must be diffused over the surface of the cavity in which the resistance is

situated, and must operate without fixed points of attachment for the fibres, so that a reticulated arrangement is obviously most advantageous. It is stated by Mr. Skey, that the middle coat of the arteries is composed of a tissue having precisely the same appearance under the microscope as the muscular tunic of the intestines; and that this is obviously different from the elastic fibrous tissue with which it has been associated. It does not seem, however, to be chemieally identical with muscular tissue, since it is entirely deficient in fibrin, which is the characteristic ingredient of the latter. Fibrin, of which the ultimate fibres of muscles appear chiefly composed, is made up, like most of the other combinations of which the animal body is constructed, of the four elements, oxygen, hydrogen, carbon, and nitrogen; but it contains a larger proportion of the last than any other proximate prineiple, and is thence considered as the most highly animalised (§ 17). It is interesting to compare its peculiar composition with the special character of its function; this being one of many facts which tend to prove that what are termed *vital* as well as *physical* properties, may be dependent upon the combination and arrangement of the elementary particles of the tissues which manifest them (CHAP. I).

44. The last of the animal tissues, the *nervous* structure, is one which has afforded a fruitful source of investigation to the microscopic enquirer, whilst the peculiarity of its functions renders it an object of especial interest to the physiologist. If any nervous trunk be carefully examined, it will be found to consist of a number of smaller filaments, connected together by cellular tissue, and enclosed in a common membranous envelope, the neurilema. These filaments, when analysed in the same manner with the minute fasciculi of muscular substance, are found to consist of tubular fibres, which are usually, if not always, perfectly cylindrical (Fig. 29) Their cavity is filled with a sort of medulla or pith, which, when squeezed from them, has a granular consistenee; but when lying *in situ*, this substanee is stated by Remak to be itself a continuous fibre, divisible into minute filaments. Their diameter varies, among the Invertebrata, from $\frac{1}{48}$ to $\frac{1}{1000}$ of a line; but in Vertebral animals the extremes are not so distant, the tubes being commonly from $\frac{1}{120}$ to $\frac{1}{240}$ of a line in diameter. A smilar fibrous structure is evident in the brain; and here the tubes seem to contain a viscous fluid, not altogether unlike the medulla of the fibres of nerves, but of less consistenee. A different strueture has been deseribed by Ehrenberg, under the name of *varicose* tubes, which he states to exist in the brain, spinal cord, and nerves of speeial sensation. These tubes were so named from their not being cylindrical, but presenting dilatations at intervals, so as to resemble a string of beads (Fig. 28); and the appearance of these dilatations has given rise to the opinion that the brain is composed of globules. It is now, however, satisfactorily shown that they are the result of

the pressure and other manipulations to which the objects are subjected in preparation for the microscope; and that, if the nervous fibres of the brain and other parts are examined in a recent state, they are cylindrical, like those of the nervous trunks in general. Still there is some difference in their structure, since they exhibit this tendency to become varicose, which is elsewhere wanting. Besides these tubular fibres, which constitute the white portions of the nervous matter, there are other filaments of a grey colour, and of much smaller diameter, without distinct cavities, which exist especially in the sympathetic nerves, but which may also be detected in others. All the fibres appear to maintain their separate continuity, from their origin to their termination, without any junction or anastomosis amongst each other; it is not uncommon, however, for two or more trunks to interchange separate filaments. This kind of connection seems to exist between the two great divisions of the nervous system (CHAP. XV), each containing some fibres which are derived from the other. In the grey substance of the brain, and in the ganglia of the sympathetic, the fibrous arrangement seems to be lost; these portions consisting of cellular tissue, and a network of blood-vessels, in the interstices of which lie a number of globules, and into which the neighbouring fibres are prolonged in loops. These globules are of large size in the ganglia, and seem connected together by little filaments, like the small grey fibres of the sympathetic nerve. In the brain, they appear broken down into more minute granules. Nervous tissue is very copiously supplied with blood-vessels, which not only form a large part of the grey substance, but ramify minutely in the trunks of the nerves; and upon the constant stimulus of the circulating fluid its functions seem to depend. Nervous matter, or *neurine*, contains a remarkable proportion of water—no less than 80 per cent.; a peculiar fatty matter into the composition of which nitrogen enters; together with some sulphur and phosphorus, the proportions of which last ingredients appear peculiarly liable to be affected by disease.

V.—*Transformation of Tissues.*

45. There exists, to a certain extent, a capability on the part of the different tissues now described, to assume each others' characteristic forms and properties. This transformation of tissues, however, is governed, like their first creation, by certain fixed laws. In particular portions of the vegetable structure, we may detect the occurrence of such changes among the regular phenomena of growth. Thus, we find vesicles of cellular tissue, which were at first isolated, subsequently becoming continuous ducts or canals, by the obliteration of their partitions (§ 24); and that this change takes place during the development of every more perfect plant, seems evident from the fact that in the embryo state no such ducts

are ever found, the whole fabric being formed of cellular tissue. Again, it seems ascertained that cells and vessels formed upon the spiral type, may present great varieties of appearance at different stages of development; the fibre which at first possessed a regular spiral form, being subsequently broken into rings or more irregular portions, so as to produce an annular or reticulated duct; and these portions at a later period growing at their edges, and uniting together to form that kind of internal sheath with numerous interstices, which constitutes a dotted duct (§ 27—29). We find in the lower parts of the vegetable scale that the function of these ducts, namely the conveyance of fluid, is performed by cellular tissue, which alone constitutes the simplest forms of plants; and it is from cellular tissue, in the higher and more elaborated vegetable fabrics, that we find these special organs gradually developed. But we never find woody fibre replacing the ducts either in situation or in function, however extensively we prosecute our examination; nor do we ever observe that woody fibre transforms itself into any kind of duct or vessel. These, indeed, appear to be modifications of cellular tissue entirely distinct from each other, although having a common origin; so that when once their character is determined, it remains fixed. Although the varieties of elementary tissue are much fewer in vegetables than in animals, we are able to trace the operation of the same general law in their development,—that the transformations which they undergo in the evolution of the embryo of the higher plants, are analogous to those which are presented to us in ascending the scale of existence, from its simpler to its more complex structures.

46. In the development of a highly organised animal fabric, possessed of a multitude of dissimilar parts, out of the simple and almost homogeneous body which constitutes its germ, it would be very interesting to trace the gradual evolution of the different tissues, as well as the organs they compose. But this subject must be here very slightly dwelt upon. It is commonly stated that all the elementary structures take their origin from cellular tissue; this is, however, scarcely correct, since the appearance of this last, as of all the rest, is preceded by the existence of a semi-transparent gelatinous matter, of which the entire embryo seems at an early period to be formed. This substance, which bears a considerable resemblance to the granular pulp of which the lowest animals are composed, is absorbed and disappears, in proportion as more definite structure is evolved; and the formation of several tissues may be observed to take place simultaneously in the midst of it. There can be no doubt, however, that cellular tissue enters into the composition of every organ in the body; and that, in all which essentially consist of it, very important modifications may take place, either during the natural stages of growth, or from the effects of disease. Thus, we find cartilage transformed into bone; membranes becoming cartilaginous; ligamentous bands becoming fibrous;—

and so on. But these transformations are governed, both in health and disease, by certain fixed principles, of which the most general (being applicable to the vegetable as well as to the animal kingdom) was stated in the last section. But this must be understood in the latter case, as in the former, with some limitations. Thus, cellular tissue may be transformed into any tissue which takes its origin from it; but this, when once fully evolved, cannot be converted into another. When this transformation takes place, it is often to fulfil some special object required by the circumstances. Thus, a new serous or synovial membrane is produced to obviate friction, where a new joint results from an unreduced fracture or dislocation; a cutaneous membrane is developed, where protection from the external air is necessary; and cartilage, where elasticity and strength are required.

47. When a regeneration occurs of parts which have been destroyed by disease or injury, cellular tissue is at first formed, which is afterwards converted into the structure that is to be repaired, or into some other which replaces it in the animal scale. Thus, a divided muscle is united by a yellow fibrous tissue, like that which in some animals seems to exist as a substitute for muscle; and cartilage, which is formed between the two ends of a broken bone, before the deposition of ossific matter, frequently supplies its place in animal structures. But although cellular tissue itself may be transformed into any of its modifications, these do not appear capable of being changed by disease into one another, excepting so far as, in the progress of embryonic life, or in the animal series, similar transformations occur. Thus, cartilage may become bone, but never mucous membrane; mucous membrane may be converted into skin, and *vice versâ*, but neither into serous membrane. Again, it is found that all tissues which are *atrophied*, or insufficiently supplied with nutriment, have a tendency to return to the condition of cellular structure. This degeneration occurs in a great variety of instances. Sometimes it forms part of the regular succession of changes which mark the advance of life; as when the thymus gland, ductus arteriosus, &c. of the fœtus shrivel up, having no longer any function to perform. Sometimes it results from disease or want of use in the organs themselves; as, for instance, where muscles which have been long inactive lose their contractile fibres. And sometimes it is observed in the animal species, where an organ which is important in one species, ceases to be so in another that is allied to it. A curious illustration of the latter kind is afforded by the *ligamentum nuchæ*, which gives such important assistance in the support of the head, where the neck is long and the head heavy, as in the horse or ox. In these animals it is distinctly composed of yellow fibrous tissue; but this structure is not so evident in the sheep, the dog, and the pig, where strength and elasticity are less required for this purpose. Few fibres are found in the ligamentum nuchæ of the cat, and in man it is entirely composed of

cellular substance; but in persons who are accustomed to carry heavy burdens on their heads, a fibrous structure may be detected. Lastly, transformations which result from disease not unfrequently tend to establish an analogy with the usual condition, in some other animal, of the part affected. Thus, it is not uncommon to find in man bony plates existing in the fibrous membrane *(dura mater)* which surrounds the brain, and especially in those projections of it (the *falx* and *tentorium)* which divide and support the different parts of that organ; and these projections exist in a state of more or less complete ossification in many quadrupeds, especially among the Carnivora. Again, the ligamentous substance which connects the muscular fibres at the base of the heart, is not unfrequently ossified by a process of disease in man; whilst in the ox and other ruminating quadrupeds, bone naturally exists there. It would be easy to adduce many illustrations of this kind; but these will suffice to show that law and arrangement preside over the adaptation of these minute parts, as over that of structures apparently more important.

VI.— *Vegetable Kingdom.*

48. It is computed that from 70,000 to 80,000 distinct *species* of plants, or races descended from different original stocks (CHAP. XIV.), exist in various collections; and probably at least as many more remain to be discovered. It is obvious that an acquaintance with their characters, structure, and mutual relations, will be much facilitated by a judicious arrangement of them; and, indeed, it can only be gained within the compass of a single life by such means. In making this arrangement, those species are first assembled into a group, termed a *genus*, which resemble each other in all the more important particulars, and differ only in minor details. Several genera may, in like manner, be united into a larger division, which shall embrace those that agree in the higher or more general characters, but differ in their special conformation. By continuing to pursue the same plan with regard to these divisions, we arrive at *orders* and *classes;* and we are at last brought, by uniting these, to certain primary divisions into which the whole kingdom may be at once distributed, each of which contains a large number of dissimilar groups united together by some common points of general resemblance. Whatever be the peculiar mode of classification, this plan is its foundation; and what are called Artificial and Natural Systems differ in this,— that the artificial method groups together plants according to their correspondence in some *one* particular character, without regard to the rest, and thus frequently brings together plants which differ extremely in character and properties;—whilst the natural aims to associate in the same division those which have the greatest *general* resemblance to each other, and the properties as well as the structure of which are found to

present a manifest correspondence. The Artificial System of Linnæus is undoubtedly the best of its kind, and the most easy of application. Its classes and orders are principally founded upon the number of particular parts in the flower; and as every tyro can count these, the place of an unknown plant in the classification may at once be discovered. But when so ascertained, no absolute information has been gained respecting the structure, properties, or affinities of the individual; and a reference to books is necessary to obtain it. A person acquainted with the characters of the Natural orders may, on the other hand, at once determine to what previously known genus a new or unknown plant is most allied, what is its place in the series in reference to others, and (which is of the most immediate *practical* importance) what are its poisonous or esculent properties. It is only by aiming to perfect a Natural System, which shall give a faithful account of the relative conformation of the immense multitude of species dispersed over the globe, that we can have any expectation of arriving at a knowledge of the laws which regulate the structure and distribution of the vegetable kingdom; and Linnæus was so sensible of this, that he framed his artificial system solely for the purpose of facilitating the accumulation of materials necessary to construct a natural method.

49. The primary division of the vegetable kingdom made by Linnæus, into Phanerogamia or Flowering Plants, and Cryptogamia or Flowerless Plants, was, however, a natural one; because the members of these groups do not agree in the single condition of the presence or absence of flowers alone, but in various other peculiarities of structure. It must be explained, however, that it would probably be more correct to speak of the Cryptogamia as plants in which only one kind of apparatus is necessary to the formation of the embryo, and of Phanerogamia as requiring two forms of reproductive organs for the production of the seed (chap. xvii.): but these organs, though usually contained together in each flower, are sometimes separated, as in Monœcious and Diœcious plants; or they may exist in an obscure form, without any of those appendages which constitute what is usually denominated a flower. The Phanerogamia have this most important difference in structure from the Cryptogamia, that whilst the former contain woody and vascular texture in abundance, the latter are almost entirely composed of simple vesicles of cellular tissue. Hence the former are frequently denominated *vascular* plants, and the latter *cellular*; but this distinction must not be regarded as holding good in every instance, since the higher Cryptogamia, such as Ferns and Mosses, possess not only a woody stem, but evident indications of vascular structure, although no true spiral vessels are found among them; and there are many Phanerogamia in which no spiral vessels can be detected. This instance is only one among many which could be produced, to show the impossibility of laying down, with regard to any

group, characters so definite as to include all its members, without at the same time opening the door for the admission of others which may present approximations to them. In fact, there is scarcely any one peculiarity of structure upon which divisions have been established, that may not be found to exist in an obscure or rudimentary form in neighbouring species. Another marked peculiarity which distinguishes Phanerogamia from Cryptogamia, is the structure of the *seed* of the former, as compared with the *spore* of the latter. A mature seed, prepared by one of the former class, contains not only the embryo of the future plant, already assuming a definite form, and exhibiting the rudiments of its future stem and root; but also one or more temporary leaves termed *cotyledons*, which assist in its development until the true leaves are evolved; as well as a store of nutriment already assimilated by the parent, which, like the albumen of the egg, supports the growing structure until it is capable of maintaining its own existence. This last part ordinarily constitutes the bulk of the seed. The *spore* of Cryptogamia, on the other hand, possesses no such distinction of parts; and the commencement of the growth of the embryo which it contains is very different from the germination of a seed.*

50. The division of the Phanerogamia into subordinate groups is very readily effected, since there are many striking points of difference which separate them into two classes. Of these, the most constant and remarkable are the structure of the stem, and that of the seed; whilst the conformation of the leaves and flowers also present some peculiarities common to the two classes respectively. The names given to these divisions, with reference to the structure of their stems, are *Exogens* and *Endogens*. The former, which includes all the trees and most of the herbaceous plants of temperate climates, is so named from the additions to the diameter of the stem being made *externally* to the part already formed. In the ENDOGENS, the division which comprehends the Palms, Canes, &c. of tropical climates, and the Grasses, with most bulbous-rooted plants of this country, the addition to the stem is made *within* the previous portion of it. The respective structures of this part will presently be more particularly described. The divisions which, previously to the discovery of this distinction, had been erected upon the character of the seed, correspond almost exactly with those just stated. Seeds usually contain either one or two cotyledons; in the former case they are termed *Monocotyledonous*, and in the latter *Dicotyledonous*. The structure of the former is illustrated in Fig. 32, which represents the seed of a lily or onion; this contains the embryo, *a*, enveloped in its cotyledon, and surrounded by the *albumen*, *b*, which is laid up for its support.

* What is the real analogue of the spore in flowering plants, will be hereafter considered (CHAP. XIII).

When germination (the incipient development of the seed) takes place, the *plumula* or young stem (*a*, Fig 33) pushes itself through the cotyledon, which continues to sheath its lower part without entirely quitting the coats of the seed. All plants which have an Endogenous stem have Monocotyledonous seeds, and *vice versâ;* so that the terms are synonymously used to characterise this great division of the vegetable kingdom. Amongst Dicotyledonous plants there is more variety in structure; for the albumen does not always surround the embryo, but is sometimes taken into its substance, rendering the cotyledons thick and fleshy. This is the case in such seeds as those of the bean or pea (Fig. 34), where the two cotyledons *a*, *a*, are seen connected by the germ of the stem and roots, which consists of the plumula, *b*, and the radicle, *c*. In the Lime Tree, Castor Oil plant, and many others, however, the albumen is a separate store, as in Monocotyledons, and the seed-leaves are thin and membranous. During the germination of these seeds, the upward elongation of the plumula carries the cotyledons to the surface, where they acquire a green colour by their action with the air, at the same time performing all the functions of leaves, until the permanent foliaceous organs are evolved (Fig. 35). The albumen, whether contained within them, or remaining within the seed, is gradually absorbed by the young plant, which, when this is entirely exhausted, is capable of maintaining its own existence. All Dicotyledonous plants are Exogenous in the structure of their stem, but the reverse does not quite hold good; for some Exogens, as the Pine tribe, have many cotyledons; and others, as the Horse-chesnut, appear to have only one. In the former case, however, it is probable that the increased number may be due to the division of the original pair; and in the latter, it is certain that there is no absence of either part, but that the cotyledons are united together, so as to resemble a single organ, being still really double.

51. We shall now consider more in detail the structure of the stem, and its differences in Exogens and Endogens. In both cases it consists in part of cellular tissue, which forms, as it were, the mould of it; and in herbaceous plants, the soft succulent axis is composed of little else. In harder stems, however, woody fibre forms a larger or smaller part; and in these we find vessels and ducts of different kinds developed to the greatest extent (§ 285). It is in the particular arrangement of these tissues, and in their mode of increase, that the difference between the Exogenous and Endogenous stems consists. The structure of the former is illustrated in Fig. 30, of which the upper part shows a horizontal or transverse section, and the lower portion a vertical section, (the same parts being represented in both under different aspects), of such a stem as the Ash, Beech, Elm, &c. In the centre at *a* is seen the *pith*, as viewed

through a microscope; this is composed of cellular tissue only, generally of a regular figure, either hexagonal or square. Surrounding the pith is a delicate membrane consisting almost entirely of spiral vessels, seen in section at *b*, *b*; this is called the *medullary sheath.* Exterior to this is the *wood*, which is composed of concentric rings, equal in number to the age of the tree. Each ring is made up of vessels and woody fibre: the vessels *c*, *c*, *c*, (whose transverse section is shown by the large apertures in the upper figure), being usually at the interior of each ring; while the woody tissue *d*, *d*, *d*, (shown by the minute apertures in the upper figure), is at the exterior, being formed in the later part of the year. Three of these rings, corresponding almost exactly in structure, are seen in the figure; indicating that the stem or branch is of three years growth. The next ring would be formed externally to the third, and thus the inner and older layers become deeply imbedded by the newer ones. It is through the ducts and woody tubes of the newer layers that the sap ascends; and the older wood is often consolidated by the deposition of resinous and other secretions, which completely fill its passages. Sometimes the line of demarcation between the *alburnum* or sap-wood, and *duramen* or heart-wood, is very distinct, as in the lignum vitæ and coco-wood; more generally however the consolidation is gradual. The alburnum soon decays if used as timber, and is therefore comparatively valueless. External to the wood is the *bark*, which is principally composed of cellular tissue, with some woody fibre. It is frequently thick and spongy, as in the cork-tree; sometimes the inner bark is formed in beautiful layers, which may be separated into a fine net-work, as in the "vegetable lace" tree of Jamaica. The bark is formed, like the wood, in annual layers, which, however, can seldom be distinctly separated from one another; but each layer of bark is formed *within* that which preceded it, and in contact, therefore, with the new layer of wood. The outer layers of bark are in most trees constantly scaling or peeling off; so that the newly formed circles are, in the process of time, brought to the surface, and fall off in their turn. One other structure of the Exogenous stem remains to be described, namely, the *medullary rays.* These are represented by the lines radiating from the centre in the horizontal section; and are thin plates of cellular tissue, closely compressed so as to appear dark, maintaining a communication between the pith and the bark. They are, in fact, the remains of the cellular tissue, which, before the first woody layer was formed, constituted the whole of the stem; and when the introduction of the first woody bundles separates the internal cellular structure, or pith, from the external portion, which composes the bark, these medullary rays or plates, (known to carpenters by the name of the silver grain), keep up that connection between them which is necessary in the economy of the plant. This structure may be made comprehensible by referring to Fig. 36, which is a vertical section

of a fossil wood, not taken in a radial line from the centre, but crossing the direction of the medullary rays;—*a*, is a large dotted duct, exhibiting the remains of their cellular partitions; *b*, *b*, represent the woody fibres, separating some of which are seen the cut ends, *c*, *c*, of the narrow plates of cellular tissue forming the medullary rays.

52. The structure of the Endogenous stem, of which corresponding sections are shown in Fig. 31, is very different. We have here also cellular tissue, woody fibre, ducts, and spiral vessels; but they are arranged, as it would seem, without any definite order. There is no distinction of pith, wood, and bark. The cellular tissue exists through the whole stem; and dispersed irregularly through it, are a number of bundles, each of which is composed of woody fibre, spiral vessels and ducts. This is shown in the horizontal and vertical sections in the figure;—*a*, *a* represents the cellular tissue existing in every part of the stem; and lying in the midst of its substance, are seen the bundles composed of *b*, *b*, spiral vessels, *c*, *c*, ducts, and *d*, *d*, woody fibre. In each bundle, the spiral vessels are innermost, the ducts external to them, and the woody fibre on the outside of these; thus, the same order is preserved as in the exogenous stem. The additions to the substance of Endogenous stems are made in the centre, where the cellular tissue is always comparatively soft and loose in its texture, and the woody bundles fewest. As new tissue is formed in the centre, that of the circumference, not having much power of yielding, becomes compressed and very dense. The outer wood of many palms is so hard as to resist the blow of a hatchet, while the interior is quite soft and spongy. Endogenous stems never increase much in diameter from the time they are first formed, but only in solidity. Sometimes the unyielding character of the outer part of the stem, occasions the vessels to be so closely compressed by the newly added tissue within, as to become impervious; and the tree consequently dies, unless the pressure be relieved by the natural or artificial splitting of the exterior.

53. We may next pass to the consideration of the foliaceous appendages of the stem, and their mode of arrangement. The *Leaves* of plants present the most remarkable diversity of form; but few are aware how much agreement there is in their general structure. Each one may be regarded as consisting of the *petiole* or footstalk, the *lamina* or blade, the *midrib*, and the *veins*. The midrib and veins, which act as the skeleton of the leaf, are considered as prolongations of the petiole; being formed, like it, of woody fibre and vessels, which are in connection with those of the stem and bark (§ 286). The mode in which the veins are distributed is, to a certain extent, characteristic of the different classes of plants. Thus, among the Cryptogamia, wherever the veins exist in a definite form, as in Ferns, they ramify by subdivision, without again uniting; hence these plants have been termed *forked-veined*. In

Exogens, the veins ramify in a manner somewhat similar, but they unite again, and by their frequent inosculation form a kind of net-work ; such leaves are said to be *reticulated.* In Endogens, on the other hand, the veins are always parallel to each other, sometimes running in the line of the principal vein or midrib, sometimes transversely to it; hence these leaves are said to be *parallel-veined.* The *lamina*, or blade of the leaf, is formed by the *parenchyma*, or fleshy cellular tissue which fills up the interstices of the veins; and according to the degree in which this is present or absent, the shape of the leaf will vary, although the distribution of the veins remains the same. Thus, in Fig. 37, all the specimens represented have the same character of *venation*, and yet seem to differ completely, owing to the variety in their filling up, These are leaves of different plants; but the same plant may exhibit great varieties, according to the degree of nutrition which it receives. Thus, the Holly will sometimes bear leaves so smooth at their edges as scarcely to be recognised; while, under other circumstances, the veins project so far beyond the parenchyma, as to have the character of prickles: the *Cochlearia* (horse-radish), of which the leaves have usually edges nearly even, will, if starved, present them deeply toothed : and in the *Dracontium pertusum*, one of the *Arum* tribe, the large expanded leaves have not unfrequently apertures in their centre. It would be foreign to the present object to enter more minutely into the general conformation of these parts of the vegetable fabric; of their special structure, in relation to the functions of Exhalation, Respiration, &c. in which they are concerned, details will hereafter be given (§ 429); and the laws of their arrangement will shortly be stated (§ 133).

54. The essential structure of the *Flower* presents but little variety in Exogens and Endogens; both possess the same parts, arranged in the same manner; the only difference is in their number, and the indications which this affords are by no means constant or definite. The flower is composed of several distinct parts, some of which are essential to the formation and ripening of the seed, whilst others are less necessary, and are frequently absent. At the base of the stalk which supports it, are often found some little leaves termed *bracts*, which are intermediate in character between true leaves, and those metamorphosed forms of the same elements, which occur in the flowers themselves. Sometimes the bracts are themselves coloured, and are much larger than the parts of the true flower, as in the Hydrangea. The coloured leafy parts of the flower are called the *floral envelopes*, to distinguish them from the essential portions of the reproductive system, and consist of the *calyx* and *corolla.* These differ more in position than in real character; for though the calyx is usually green, and the corolla coloured, (all shades, even *white*, being regarded as colours in Botany, to the exclusion of *green*,) there are many plants

(as for instance those of the tulip tribe), in which the *sepals* or leaflets of the calyx, are as brightly coloured as the *petals* or leaflets of the corolla, or, at most, have only a greenish tint externally. The sepals of the calyx are often found uniting together at their edges so as to form a cup; and the petals, though more frequently distinct, are not by any means free from liability to a similar adhesion. This may take place wholly, so as to form a complete cup or tube; or partially, so as to leave the evidence of their original separation. The forms which both calyx and corolla assume, are very much diversified; and frequently the regularity and distinctness of their parts seem altogether lost. It will seldom, however, be difficult to discover their real characters; since intermediate forms are almost always to be detected, which establish the true analogies of their parts. It is in this manner, too, that it may be shown that both sepals and petals are but modifications of the same elements of which leaves are formed; for independently of their conformity in ultimate structure, there are many flowers, such as the double pæony, in which the transition from leaf to bract, from bract to sepal, and from sepal to petal, is almost imperceptible.

55. Within the corolla of most flowers is seen a circle of little yellow bodies mounted on long stalks, which are called the *stamens*. Each stamen is formed of its thread-like stalk or *filament*, and the two-celled *anther* which it carries. This is seen in Fig. 38, where *a* represents the anther-lobes of the lily. These contain a quantity of little yellow grains termed *pollen*, which have an important office in the reproductive process (CHAP. XIII.); and when these are mature, the anthers burst, sometimes along their length as at *a*, sometimes transversely as at *b*, sometimes by little openings at the end termed *pores* as at *c*, sometimes by *valves* as at *d*. Although it would seem strange to assert that stamens are metamorphosed leaves, yet the assertion is easily proved by reference to such plants as the white Water Lily, where the transition from the form of the petal to that of the stamen is very gradual; as well as to the fact that in flowers rendered double by cultivation, a part or all of the stamens are converted into petals. In the centre of the flower stands the organ termed the *pistil*; which, although it frequently appears single, may be properly regarded as made up of separate parts, more or less completely united together. The pistil is composed of the *ovarium* or seed-vessel, at the base; upon this is a column termed the *style*, which is expanded at the top into a fleshy surface called the *stigma*. The ovarium is composed of a number of *carpels* or divisions, more or less closely united together. Fig. 39 represents the pistil of a flower in which the carpels remain disunited, each possessing its own style. Three carpels only are seen, the other two being concealed behind them, but their styles are shown. The structure of a single carpel of the double cherry, which, when cut across, exhibits the ovules or young seeds within

it, is shown at *a*, Fig. 40; and *b* shows a *monstrous* form of the same part, which, with other similar productions, proves that each carpel is a modified leaf. The leaflet here shown, presents the appearance of a half developed carpel, the midrib being prolonged and dilated, somewhat in the form of a style and stigma, and the edges being partly turned towards one another. Another form of the pistil, in which all the carpels with their styles have completely united, is shown in Fig. 41, which is a section of that of the *Vaccinium amœnum* (whortleberry). The calyx, *a*, is seen to have here grown round and inclosed the ovarium, *b*, as happens in the apple and many other fruits. The ovules are seen arranged on the central column formed by the clustering together of the inner edges of the carpels; and the single style, *c*, terminated by the stigma *d*, is seen surmounting the ovarium. At Fig. 42, is shown another seed-vessel similarly enveloped by the calyx; in this all the partitions formed by the sides of the carpels (such as occur in the orange) have given way, and the central column alone remains, round which the ovules are clustered. In the ovarium of the *Viola tricolor* (heartsease), represented at Fig. 43, the partitions are also obliterated, but the ovules are attached to protuberances in the sides of the cavity. Of the respective offices of these parts in the function of Reproduction, an account will be given under that head (CHAP. XIII). It must be borne in mind, however, that the union of the two sets of organs in the same flower is by no means constant, although it may be regarded as the regular structure. Sometimes the stamens and pistils are developed in different flowers on the same plant, which is then said to be *monœcious;* when they are borne by different individuals, the species is considered *diœcious.* It is interesting to know, however, that in many instances (probably in all) where there is only one system developed, the other is present in a rudimentary state; and its evolution may frequently be produced by some change in the condition of the plant. It has been said that the difference of the flowers of Exogens and Endogens is only marked by the numbers of their respective parts. The typical number which prevails in the former class is either four or five, the petals, stamens, &c. presenting themselves either in one of those numbers, or in some multiple of it; whilst the number three prevails in the parts of the flowers of Endogens. It is very common, however, to meet with some irregularity in these numbers, for there are few flowers, among Exogens particularly, which have *all* their parts arranged with perfect uniformity.

56. Having thus given a general description of the structure of flowering plants, and of the peculiarities of their great divisions, we might proceed to investigate their subordinate groups; but although botanists have succeeded in combining individual plants into natural orders, each of which contains the species which are allied to each other in structure and correspondent in properties, yet they have not agreed upon the mode

of forming these into larger groups, which shall be natural subdivisions of the primary classes. It will be better, therefore, to leave the subject undiscussed for the present; and there is the less objection to the omission, as there do not appear to be any marked structural or functional differences in these subordinate groups, to which we might subsequently have to refer. It should be mentioned, however, that several orders of Exogens appear to be closely allied to others among Endogens, in various particulars; but the transitions presented by some particular groups to the structure of the Cryptogamia are extremely curious, and must be noticed more in detail.

57. The *Gymnospermæ* or naked-seeded plants, are a class of which some members have been included amongst Exogens; corresponding with them in the general structure and growth of the stem, but exhibiting the reproductive system of flowering plants in its very lowest degree of development. The best known order which the class includes, is that of the *Coniferæ* or Pine tribe. The lofty stems of these trees are composed almost entirely of that peculiar form of woody fibre termed *glandular* (§ 25), without perfect spiral vessels, and with an almost total absence of ducts of all kinds. The organs of fructification are separated, and evolved in their simplest form, for nothing like a calyx and corolla are present; but the ovules are situated upon the open hollow of the scales of the cone, which are regarded as ovaria, and are destitute of anything like style and stigma; and the stamens appear as metamorphosed forms of scales not very dissimilar. The connection between this group and the order *Lycopodiaceæ*, which may be regarded as among the highest of the Cryptogamia, is beautifully established by certain fossil *Lepidodendra;* and it is not impossible that other no less beautiful transitions may become apparent, when the places of various groups shall have been fixed by an enlarged acquaintance with their structure. Another order of this class, the *Cycadaceæ*, exhibits, in the general aspect of its members, and in some particulars of their structure, no small resemblance to the Palm tribe among Endogens.

58. The peculiar connection between Endogens and Cryptogamia is established, however, by a group still more curious,—that of *Rhizantheæ.* If a Botanist had been asked how he could unite the structure of flowering and flowerless plants, of Endogens and Fungi, so as to form an intermediate family, he would undoubtedly have been much perplexed; but in this curious group the hand of Nature presents to us the solution of the problem. Like Fungi, these plants are parasitical upon the roots and stems of others; and they agree with that order in their fleshy succulent texture, in their lurid colour, and often in their putrid odour when decaying, as well as in the character of their seeds, which do not appear to possess any distinct embryo, but more to resemble a mass of spores. They possess, however, spiral vessels; and, from the presence

of distinct organs of fructification in their flowers, they must be reckoned as allied, at least to the Phanerogamia, and especially to Endogens. As an illustration of the characters of this tribe may be mentioned the *Rafflesia Arnoldi*, one of the most extraordinary productions of the vegetable world (Fig. 44). It was discovered in the year 1818, in the interior of Sumatra; and it has not been found elsewhere, except in the adjacent islands. The plant, which is *all flower*, (in this respect corresponding with the Fungi, in which the reproductive system is predominant), grows upon the creeping roots or stems of a species of Cissus, looking when young like an excrescence from the stalk on which it grows. This protuberance is in reality a sort of leaf-bud, consisting of a number of scales folded over the flower, which subsequently bursts its envelopes, and grows to an enormous size. The petals of the specimen first found were each 12 inches long, of a very succulent and fleshy substance, being from a quarter to three-quarters of an inch in thickness. When first seen, a swarm of flies were hovering over it, and seemingly preparing to lay their eggs in it; being apparently deceived by its smell, which was precisely that of tainted beef. This extraordinary flower measured a full yard across, the distance between the insertions of the opposite petals being 12 inches; and its weight was about 15lbs. When unexpanded this vegetable monster is as large as a middle-sized cabbage, and it only takes about three months for its complete formation.

59. Amongst the true CRYPTOGAMIA, the class which most nearly approaches flowering plants is that of the FERNS. In temperate climates, its members never elevate themselves much above the ground, and indeed never present a true vertical stem; that which appears to be such being really a leaf-stalk, sent up from the *rhizoma*, or horizontal stem, which creeps at or near the surface of the earth. This is well seen in the *Davallia canariensis*, or Hare's-foot fern. In tropical climates a true woody stem is often evolved, which sometimes rises to the height of forty-five or fifty feet, and is surmounted by a magnificent crown of fronds or leaves. The structure of this stem differs much from that of either Exogens or Endogens. An external view and section of it are seen at Fig. 45, where it is shown to consist of thin plates of very hard woody structure, partially cohering together; the interior is usually hollow, or is filled, if solid, only with the same spongy substance as that which lies between the woody plates. These plates never increase in thickness, number, or quantity, after being once formed; and they appear to be nothing more than the persistent leaf-stalks of former circles of leaves, the scars left by the decay of which are seen on the exterior. A new circle is formed every year at the top of the stem, which thus goes on increasing in length; whilst the lower and older part of the trunk seems to undergo little or no change, except, perhaps, some elongation. From this mode of growth by addition to the point or extremity of

previously formed parts, which seems common to all the Cryptogamia possessed of anything like a distinct axis, the term ACROGENS has been applied to the members of this division, for the purpose of bringing it into contrast with EXOGENS and ENDOGENS. Ferns present no form of fructification which has an evident analogy with flowers; but their corresponding organs are very interesting. The spores, (commonly supposed to be the equivalents of the seeds of Phanerogamia*), are contained in little cases of very curious structure termed *Thecæ*, which are developed on some part of the under surface of the leaf, being always connected with its veins. Each *theca*, in its most perfect form, is mounted upon a little stalk, which is continued round its circumference in the form of a ring; and this, by its elasticity, separates the divisions for the escape of the spores when ripe (Fig. 46). In some species, however, the theca is destitute both of a footstalk and of a ring, and is simply implanted on the leaf. The thecæ are usually arranged in clusters, termed *sori;* and these are sometimes circular (Fig. 47, *a*), sometimes linear, as at *b*, and sometimes confined to the edge of the leaf. In some forms of this group, such as the *Osmunda regalis*, (or flowering fern, as it has been incorrectly termed,) which is the handsomest of the British species, the sterile or leafy fronds are distinct from the fertile or spore-bearing ones, the latter losing their leafy aspect by the contraction of their margins around the thecæ. This distinction also exists in the *Ophioglossum*, (adder's tongue); here the thecæ are altogether wanting, the spores being inclosed in segments of the leaf, which are folded in to embrace them (Fig. 48). Of one of the orders which have usually been ranked among Ferns, or as allied to them, the *Marsileaceæ*, we shall speak more particularly at a future time (§ 524). The *Lycopodiaceæ*, or Club-Moss tribe, appear intermediate between Ferns and Coniferæ on one hand, especially through their fossil allies; and between Ferns and Mosses on the other. They are related to Coniferæ by the structure of their stems, especially those of their larger kinds; and to Ferns in the abundance of the annular ducts contained in them, as well as in the characters of their reproductive system, about which there is, however, some uncertainty. Their general aspect most resembles that of the Mosses, especially when the stems are creeping, and the leaves imbricated, or folded over each other. Their system of fructification consists of *Thecæ*, containing two kinds of reproductive bodies, the relative offices of which are not known. The powdery matter which constitutes one of these, goes under the name of vegetable sulphur; and from its peculiar combustibility, taking fire with a flash when diffused through the air, it is employed at the theatres, &c. for the purpose of producing artificial lightning.

60. The next group of Cryptogamia, that of MOSSES, is as interesting

* Into their real character we shall enquire in the proper place § 519.

from the delicacy and minuteness of the plants composing it, as other tribes of the Vegetable Kingdom are from their majestic port or the wide extension of their foliage. In them we find no decided appearance of any other than cellular tissue, although what may perhaps be considered rudimentary forms of vascular structure are not unfrequently seen. They never shoot up woody stems; but they still possess a distinct axis of growth, around which their minute leaves are arranged with great regularity. Their leaves present the appearance of veins; these are not formed, however, of woody fibre and vessels, as in the higher classes, but only of a prolonged form of cellular tissue; and their surfaces are not furnished with stomata, except in a few instances. Their organs of fructification bear no evident analogy with those we have yet examined; their structure is, however, very interesting and beautiful. The *theca*, or *urn*, (Fig. 49, *a*) containing the spores, is closed by the *operculum*, or lid, *b*. The mouth of the urn, when the operculum is taken off, is found to be surrounded by a delicate fringe, *c*, termed the *peristome*; this is either single or double, and frequently presents colours of great brilliancy. In the centre of the thecæ is the *columella*, *d*; around this are clustered the spores, which are afterwards to be dispersed by the separation of the parts of their envelope in various ways.—These constitute the unequivocal fructifying organs of Mosses; but there are others whose nature is not altogether understood, and which have been imagined to approach in function the anthers of flowering plants, whilst the Theca has been supposed to correspond with the pistil and ovarium. In the opinion of most eminent Botanists at present, however, these anthers have no relation in function with the thecæ, but contain little germs, which separate from the parent plant, under the form of buds or gemmules. There is no doubt that these are capable of maintaining an independent existence, throwing out roots when they drop upon the ground, and soon increasing into new plants. A still more evident provision for multiplication, by a method of this kind, will be seen in the next group, the Hepaticæ. In elegance and beauty of structure, Mosses are not exceeded by any plants that grow. They have, at the same time, a remarkable power of resisting injurious influences which would be fatal to the growth of other plants; and of preserving their vitality, like seeds, when to all appearance dead. Gleditsh is stated to have revived a moss which had been dried for a hundred years, by immersing it for a few hours in water. Where such tenacity of life exists, vital actions are usually excited by very feeble stimuli; and we find that Mosses can struggle for existence on the most barren soils, and under a deficiency of light and heat which no other plants, but those of the simplest organisation, could support. They are, therefore, among the first vegetables which clothe the soil with verdure in newly-formed countries; and they are the last to disappear when the atmosphere ceases to be capable of nourishing vegetation.

61. Closely connected in many respects with the Mosses, is the tribe of *Hepaticæ*, or liver-worts, the lower forms of which pass by no very interrupted gradation to the Lichens. Some of them differ but little in general characters from Mosses, except in the mode in which the theca opens to liberate the spores, and in the presence of *elaters* (elastic spiral filaments closely coiled up) amongst the latter. Others, again, have no vertical axis of growth, but extend horizontally into a flat foliaceous expansion, which is termed the *thallus;* and in some of the lowest of these, the thecæ are not elevated upon footstalks of any kind, but are imbedded in the substance of the thallus, like the reproductive organs of Lichens. Although their general habits are the same as those of mosses, yet there are some peculiarities of structure which have been made the subject of close examination, and have well repaid the observation which has been bestowed upon them. Among these are the very curious *stomata* of *Marchantia polymorpha*, which will be more particularly described hereafter (§ 429), and the beautiful urns or baskets in the same plant for the evolution of the gemmæ or buds. These appear to be quite independent of the special fructifying system; and the little bodies (Fig. 50) which they contain, may be seen to grow whilst still contained within their receptacle, and even to unite themselves, as it were, with the parent plant. The study of their development in the hands of Mirbel has led to some very curious results (§ 180). The thecæ in this plant are arranged upon the circumference of a round *pelta*, or shield, which is considerably elevated above the surface (Fig. 53). "The liver-worts, like their allies the mosses, which often appear to have so suddenly clothed a barren heath, or overspread a dry wall with verdure, have the peculiar property of remaining in a dormant state for a very considerable length of time, and revive from their parched condition (as if awakened from sleep) on the access of moisture, to all their pristine beauty, spreading abroad their delicate leaf-like expansions, and their beautiful apologies for blossoms."

62. A very curious little group of plants, the *Characeæ*, may next be noticed; although there is much uncertainty as to its exact place in the scale. Each individual composing it is formed of an assemblage of long tubular cells placed end to end; with a distinct central axis, around which the branches are disposed at intervals with great regularity (Fig. 54). No trace of vascular structure can be detected in them; and as far as their organs of nutrition alone are concerned, they would seem almost on a level with the simplest cellular plants, and especially the Confervæ (§ 69) to whose structure they bear a great resemblance. In one of the genera, *Nitella*, the stem and branches are simple cells, which sometimes attain the length of several inches; whilst in the true *Chara*, each central tube is surrounded by an envelope of smaller ones. Some species have the power of secreting carbonate of lime from the water in

which they grow, if this be at all impregnated with calcareous matter; and by the deposition of it beneath their tegument, they have gained their popular name of *Stone-worts*. The peculiar circulation of nutritious fluid within these tubes, to which so much attention has recently been paid, will be described in its appropriate place (§ 353). It is in their organs of fructification, however, that the Characeæ seem to rank above those tribes, with which the very simple structure of their other parts would associate them. As the true character of these organs has not yet, however, been ascertained, it is not desirable to enter here into a description of them.

63. The characters of the three lowest groups of Cryptogamia, the FUNGI, LICHENS, and ALGÆ, approximate so closely to each other, that it is not easy to define them, by reference to their structure alone. They are all entirely composed of cellular tissue, and in the evolution of their reproductive system hardly seem to differ essentially. In fact, the lowest tribes of each pass into one another by almost insensible gradations. The peculiar character of the FUNGI, or Mushroom tribes, consists in their habitation, which is always upon dead or decaying organised matter; and in the predominance of their reproductive system, no *thallus* or foliaceous expansion ever existing independently of the part which bears the spores. LICHENS grow upon living vegetables, earth, or stones, in situations where they are fully exposed to light, and are not too abundantly supplied with moisture; the tendency in them is to the formation of a thallus, of which the upper surface usually presents itself as a hard dry crust, whilst in certain parts of it, *asci*, or tubes containing spores, are united into *shields*, which are distinct from the remainder of the expansion. If Lichens are removed from the influence of light, and are over-supplied with moisture, they then show a tendency to the extension of the vegetative or foliaceous portion of the thallus, and to the non-production of the fruit. This is what occurs in ALGÆ or sea-weeds, all of which are inhabitants of water, and which are scarcely distinguishable by any other positive character from Fungi and Lichens, than by the predominance of their nutritive system over the reproductive organs. All, however, meet in such simple forms of vegetation as the *Protococcus* 59 *nivalis* or red snow (Fig. 57), the *Palmella cruenta* or gory dew, the *Nostoc* or fallen star; these consist of simple aggregations of vesicles without any definite arrangement, sometimes united, but capable of existing separately; and by their own rupture give independent existence to the rudiments of new individuals contained within them. By some they have been placed among the Algæ, by some termed Fungi, and by others Lichens; the real truth appears to be, that in beings of such simplicity there are no definite characters by which their affinity to one group or another is particularly indicated; and that they are to be regarded rather as the sketches or rudimentary forms of more perfect

structures. It does not seem an improbable conclusion from certain observed facts, that the same germ, among these lower Cryptogamia, may assume several forms usually regarded as distinct, according to the circumstances under which it is developed (§ 65).

64. The tissue of the FUNGI is generally soft and succulent, and its duration transient. These plants are almost always found growing upon dead or decaying animal or vegetable substances; and where they appear unequivocally upon living bodies, there is much reason to believe that they are generally the indications of a state of previous disease, which, by the unhealthy nutrition of the tissues, has prepared a similar *nidus* for their development. In their simplest form they are little jointed filaments, composed of cellules laid end to end, or collected in a mass under the cuticle of leaves or other parts; such are all the varieties of Mould, Mildew, &c. In some of these the joints separate, and each appears capable of reproduction; in others the cellules which contain the rudiments of the new plants are collected at one extremity, whilst the others serve as a stalk (Fig. 56); and in the higher forms of this group, these fertile cells are collected within a special membranous envelope. Other Fungi, again, have a more determinate figure, usually rounded; and in their substance the sporules either lie loosely mixed with filaments, as in the *Lycoperdons* or puff-balls, or contained in membranous tubes, like the *asci* of Lichens. In their most complete state, exemplified in the Agaric or Mushroom tribe, there is a distinct stem or axis evolved, which separates the reproductive apparatus contained in the *pileus* or cap, from the nutritive or absorbent system of the root; in these, the spores are contained in tubes, imbedded in the *hymenium* or fructifying membrane, that constitutes what are termed the *laminæ* or gills, on the under surface of the pileus (Fig. 57). Thus, a progressive complication of form may be observed, without any alteration of the original characters of the simpler members of the group. The Fungi spring up with extraordinary rapidity, often acquiring the volume of many cubic inches in a single night; and they are commonly observed to appear suddenly after thunder-storms or some other meteoric changes. From these circumstances, and from the remarkable certainty of their appearance upon decaying organised matter, wherever it exist, many have been disposed to question the development of Fungi from distinct germs, and to imagine that they are generated by the processes which are antecedent to their manifestation. It is stated in support of this doctrine, that it is possible to increase particular species with certainty, by exposing a certain mixture of organic and inorganic matter to atmospheric changes, as in the process adopted by gardeners for raising the edible Mushroom; and that particular species of parasitic fungi are confined to particular leaves. It certainly is not easy to answer the questions which thence arise, why no kind of fungus but the *Agaricus*

campestris should arise upon the *Mushroom-spawn*, as it is termed,—why no *Puccinia* but the *Puccinia rosæ* should be found upon rose-bushes,—why this species should never be seen elsewhere,—and so on. As this is one of the most entertaining enquiries in Vegetable Physiology, and has an important bearing upon general science, we shall examine it a little more in detail.

65. In the first place, then, it may easily be proved, that, in all the true Fungi, the reproductive system is developed to such an extraordinary extent, that the number of germs liberated from a single plant almost defies calculation. Of this any one may convince himself by examining a puff-ball in a state of maturity. On this subject Fries states, "The sporules are so infinite (in a single individual of Reticularia maxima I have counted above 10,000,000), so subtle (they are scarcely visible to the naked eye, and often resemble thin smoke), so light (raised, perhaps, by evaporation into the atmosphere), and are dispersed in so many ways, (by the attraction of the sun, by insects, wind, elasticity, &c.), that it is difficult to conceive a place from which they can be excluded." According to this view, then, the germs of all kinds of fungi are constantly floating in the atmosphere, and one species or another developes itself, according as the nature of the decomposing matter is respectively adapted to each. It is impossible to deny that this may be the case, however improbable it may seem; there are, however, some other circumstances to be taken into account, which may lead us to adopt the opinion in a somewhat modified form. A series of facts equally important with those just alluded to, have lately been brought to light by the researches of some German Cryptogamists, who maintain, apparently on good grounds, that the same germ may assume widely different forms according to the circumstances which influence its development; thus, Fries asserts that out of the different states of one *species (Thelephora sulphurea)*, more than eight distinct *genera* have been constructed by various authors. It would seem, then, that the absolute number of species among the Fungi is not nearly so great as has been usually supposed; and that the kind produced by a decomposing infusion, or a bed of decaying solid matter, will depend as much upon the influence of the material employed, as upon the germ itself which is the subject of it.

66. Another very important enquiry has lately been suggested; namely, whether all the fungoid growths on the surface of living plants are really such, or whether they may be regarded as degenerations of the tissue upon which they are found. Unger, a German botanist, has argued with considerable ingenuity,* that the appearances termed blight, mildew, smut, &c. or more technically *Uredo*, *Œcidium*, *Puccinia*, *&c.* are to be considered as the *Exanthemata* (eruptive fevers), of vegetables, being essentially diseases of the stomata. He points out that they are

* Annales des Sci. Nat. 1834.

most liable to occur on those portions of plants where vegetation is most active, as on the green parts in general, and on the leaves in particular; and he remarks that on the surface of the healthy bark, we find either more perfect Cryptogamia or Phanerogamic parasites. The cellular parasites evidently flourish best when the bark is approaching decay; and it may be often remarked on an old tree, that whilst the stem and principal branches are covered by mosses and lichens, these diminish and disappear as we advance towards the younger and fresher portions. The presence of these morbid appearances, seems connected with that of the stomata; and it has been supposed to be from some obstruction to their functions, that the exanthemata arise. They usually appear at the season of the most active vegetation, namely, the spring and early summer; whilst the period of the most rapid development of the true Fungi appears to be the autumn and the commencement of winter. Admitting, what perhaps it would be difficult to controvert, that these morbid growths really possess the characters of this class (a statement which is based, not merely on external appearance, but on their structure and chemical composition), still it remains a question, which we are yet scarcely in a condition to answer without reserve, either in one way or the other, whether plants of a high degree of organisation are capable of producing, by diseased action, from various parts of their tissues, beings which present the characters of inferior orders (§ 517). However absurd some might think it, to answer such a question in the affirmative, it is to be recollected that all our knowledge of the laws of reproduction is founded upon a limited experience in the higher orders of the organised creation; and that in the extension of these laws to the inferior tribes, very important modifications are shown to be necessary. We shall hereafter see that the function of reproduction may be considered as only a peculiar modification of that of nutrition; and if its *regular* performance leads to the evolution of germs, which, when developed, resemble the parent, it is not irrational to suppose that it may be so far perverted, as to give origin to beings of simpler organisation. To this question we shall return when speaking of the corresponding parasites among the animal kingdom. That these *entophytic* Fungi may be communicated from one plant to another, has been fully ascertained by the experiments of Decandolle and others. It is usually imagined that the germs liberated by one plant are taken up by the roots of others, and being carried along the current of sap, are deposited and developed in the parts where vegetation is most active; perhaps, however, they may find a shorter entrance into the cavities of the fabric, by means of the stomata, these being the precise situations where they are subsequently manifested. Finally, it appears probable that many reputed fungi, such as various Rhizomorpheæ, are accidental and irregular expansions of the tissues of

flowering plants which become deformed through growing in the dark, as in cellars, caverns, &c.

67. Amongst the most important to man of all the species of this extensive group, (including probably between 4,000 and 5,000 which have been described, and many more of the tropical kinds, which, from their perishable nature, have not been subjected to accurate examination), are those which constitute *dry-rot*, such as *Polyporus destructor*, *Merulius vastator*, *&c.* The minute fibrils of these fungi insinuate themselves between the fibres of the wood on which they grow, separate and soften them, and thus bring on premature decay; for the further they insinuate themselves, the more easily can air and moisture gain access; and as the successive crops of spores develope themselves in these chinks, larger and larger clefts are formed. The distensile power of some Fungi is so great, as to raise heavy stones beneath which they grow, and to rend the trunks of large trees. In one instance which occurred in the town of Basingstoke, a paving-stone twenty-one inches square, and weighing eighty-three pounds, was raised an inch and a half out of its bed, by a toadstool six or seven inches in diameter; and nearly the whole of the pavement of the town was disturbed in a similar manner.

68. The hard persistent crusts of LICHENS, which seem scarcely to undergo any alteration in the lapse of many years, contrast forcibly with the fugitive character of the last class. There can be little question that the greater part of this tribe derive their nourishment from the atmosphere and its contained moisture alone; flourishing, as they do, upon sterile rocks, without a particle of previously organised matter in their neighbourhood. There are some species which usually grow upon trees, without seeming to derive any more nutriment from them than the moisture of their surface; since they will flourish equally well on a damp wall. There are other species allied to the Fungi, however, which vegetate on matter already undergoing decomposition, or preparing to decay. An attempt has been made to prove that some particular kinds of Lichens are confined to certain trees; and much has been written on their use in distinguishing the different kinds of bark, especially those of the Cinchonaceæ. It may be doubted, however, whether this difference is not principally due to locality, and to the adaptation of the quantity of the superficial moisture and exposure to light, furnished by different trees, to the wants of the respective species of Lichens; since there is no reason to believe that they imbibe any of the proper juices of the plants to which they adhere. It is well established that by far the greater number vegetate indifferently on all kinds of trees, as well as upon rocks; but there is no doubt that some trees bear them in much greater abundance than others. Thus, the Beech, Elm, Sycamore, and Lime, are comparatively seldom found infested with the common *beard-*

moss, which clothes so profusely the Fir, Ash, Oak, or Birch; so that the poet's epithet of "rude and moss-grown beech" is by no means appropriate. The early development of the Lichens, is favoured by darkness; but, for their ultimate perfection, a considerable quantity of light is required. The development of the *shields*, which is occasioned by exposure to this agent, is frequently accompanied by so great a change in the general appearance of the plant, that the same species growing in dark and moist places, in which the fructification was not evolved, has been considered to belong to a distinct genus from the perfect specimen. There seems, indeed, from late observations, to be nearly the same uncertainty of form among the Lichens, as prevails in the Fungi; the same germs presenting many different appearances, according to the mode and degree of their development. The sporules which are developed from the shields, appear capable of multiplying the species; whilst the powdery matter, which is frequently produced in little cup-like bodies raised above the surface of the thallus, as well as the separated particles of the plant itself, appear capable of independent existence, in various less definite forms (Fig. 58).

69. We now arrive at that which is usually regarded as the lowest tribe of the vegetable creation, and some members of which present the greatest approximation to the Animal kingdom. The ALGÆ or Sea-weeds are distinguishable from Lichens and Fungi, more by their aquatic habitation and its consequent influence on their growth, than by any definite character. Like the Fungi, they present many grades of organisation. Thus, the Protococcus, Palmella, and other species, which constitute the greenish or reddish mucous slime that is often seen on the damp parts of hard surfaces, closely resemble the lower tribes of Fungi; being nothing but an aggregation of solitary cells, (each of which may be regarded as a distinct individual), in the midst of a semi-fluid matter, which partly or wholly envelopes them (Fig. 59). Proceeding a little higher, we find these united into filaments, but still preserving the power of separation, as in the *Diatoma tenue* (Fig. 60); and higher still are the true *Confervæ*, in which the vesicles are permanently united, and enveloped in a common membrane (Fig. 61). It is in this section, that we find some of the most remarkable instances of spontaneous motion, occurring in the fully developed plant. The Oscillatoriæ exhibit very uniform and evident vibrations; the Fragillariæ, to which the Diatoma belongs, have no apparent motion as long as the riband-like threads remain entire, but separate with a sort of starting movement; and many other instances might be mentioned. The more complete Algæ, or *Sea-weeds* properly so called, assume very definite forms, the cellular tissue which composes them being arranged with great regularity; and they sometimes attain an enormous extent of development, forming vast submarine forests of the most luxuriant vegetation. Thus, the *Chorda filum*, a species common

in the North Sea, is frequently found of the length of thirty or forty feet; and, in the neighbourhood of the Orkneys, it forms meadows through which a boat forces its way with difficulty. This is nothing, however, to the size of the prodigious *Macrocystis pyrifera*, which is reported to be from 500 to 1,500 feet in length; the long and narrow leaves having an air-vesicle at the base of each, the stem not being thicker than the finger, and the upper branches as slender as common packthread. This development of the nutritive surface takes place at the expense of the fructifying apparatus, which is here quite subordinate; its structure will be detailed hereafter. Algæ pass into Lichens by the Lichenoid species of the former, which vegetate on rocks occasionally submerged by the tide. These two orders, so closely resembling one another in every character but their locality, may in a philosophical arrangement be classed together under the term of *Protophyta* or simplest plants; whilst the Fungi, which are separated by their habitation, reproductive system, and other peculiarities, constitute a distinct group. It is to be noticed with regard to the last-named order, that though they approach more nearly to the animal kingdom in chemical composition than any other tribe of plants, they present few instances of that power of spontaneous motion, which is so remarkable a characteristic of the Algæ. Much difficulty has naturally arisen from this tendency, in drawing the line between the two kingdoms; since it is in many instances impossible to determine the precise character of the motions perceived, and structure often affords no definite and satisfactory information. There are, therefore, many tribes whose place in the scale has not yet been determined. It is curious that among the Diatomeæ, we should find the same kind of affinity to the Mineral kingdom, as is indicated in the massive calcareous skeletons of the Polypifera; their joints containing large angular crystals which occupy a large part of their cavity.

70. The affinities of the principal divisions of the Vegetable Kingdom may be generally expressed in the following manner:—

EXOGENS. . . . . ENDOGENS.

Gymnospermæ. Rhizantheæ.

Ferns, &c.—Protophyta.—Fungi.

ACROGENS.

Starting from the simplest Algæ and Lichens, we may pass, on one side, through the Hepaticeæ and Mosses, to the Ferns, the highest among the Acrogens or Cryptogamia. From Mosses and Ferns the transition is easy to Exogens, through Lycopodiaceæ and Gymnospermæ. Exogens and Endogens have many connecting links; and from the latter group,

the return to the Fungi is direct by the Rhizantheæ; whilst the simplest forms of the Fungi bring us back again to the Protophyta.

VII.—*Animal Kingdom.*

71. A similar cursory view of the Animal Kingdom will now be taken, with the object not only of furnishing a key to subsequent descriptions, but also of pointing out the very curious links of affinity, by which the respective groups are connected, and which demonstrate in so evident a manner the Unity of the Design with which the whole system was constructed. The following passage, from the writings of a distinguished Zoologist, seems peculiarly applicable as an introduction to this subject. "No one who believes in the existence of an Omnipotent Creator, can suppose for a moment, that the innumerable beings which He has created were formed without a plan. If an architect sat down and made innumerable models of cornices, entablatures, columns, friezes, and all those ornaments used in a stately building, yet without any design of subsequently combining them, we should naturally say, however much we might admire the parts, that his work was imperfect. Let us apply this reasoning to the Creation: however perfect an animal may be in its structure, it would still only resemble one of the ornaments we have just alluded to. It is beautiful in itself; but it is only when we attain some glimpse of the station it occupies with its fellows, and of the manner in which it is combined into one great *whole*, that we see this beauty in its true light. No rational being can therefore suppose that the great Architect of the world has created its inhabitants without a plan."*

72. Now, to discover this plan,—by ascertaining the laws by which such infinite variety of form is combined with such general uniformity of structure,—is the object of the researches of the Naturalist (§ 6). It is obvious that it would be useless to look for their attainment in any process, which does not include a very comprehensive survey of the whole animal kingdom, and which does not found its arrangements upon a general view of the structure and functions of each group, rather than upon any individual peculiarities. From the more intimate relation however, which subsists between the different functions of animals, than amongst those of plants, it will often happen that a classification which is really artificial (§ 48), because based on the indications afforded by a single character, may be also natural. Thus, the division of the Mammalia by Linnæus, into orders founded upon the arrangement of the teeth, was really a most natural one; because the adaptation of the teeth to the carnivorous, herbivorous, insectivorous, or omnivorous habits of the animal, and to the several varieties of these, is necessarily accompanied by an adaptation of their general structure to their

* Swainson on the Geography and Classification of Animals, p. 319.

respective methods of obtaining their food, and of converting it to the purposes of nutrition. Again, it may happen that some particular external character is so constantly associated with certain peculiarities of internal conformation, that from the appearance of the one we may predicate the existence of the other, although no essential or necessary connection between them can be discerned. Thus, a Naturalist on hearing that a particular specimen is supported on two legs only, and is covered with feathers, at once knows that it is a Vertebrated animal, possessed of warm blood, a complete double circulation, highly developed lungs, complicated digestive apparatus, oviparous in its reproduction, destitute of teeth but furnished with a horny bill—in short presenting all the characters peculiar to the class of Birds. But this knowledge is simply the result of his experience, that no animal possessing different internal structure is ever covered with feathers; and he cannot assign any direct reason for this invariable connection. When, however, the habits of the animal are taken into account, the structure of the feathers may, to an acute Ornithologist, be a pretty certain indication of the place of an unknown bird in the scale; for he can judge from their peculiarities whether it belong to a family remarkable for its strong and rapid, or its slow and heavy flight; or whether, as in the case of the Ostrich tribe, the wings are altogether undeveloped. In the former case the possession of feathers is a peculiarly artificial character; whilst in the latter, their conformation has an evident bearing on the general peculiarities of the species, and must therefore be admitted as of importance in a natural classification; since it is obviously important for the practical employment of any system whatever, that its divisions should be *indicated* by easily-recognised external marks, although they can only be *founded* upon a full comparison of internal structure. It is the object of the naturalist, therefore, to discover what peculiarities of external appearance are *constantly* associated with differences in internal conformation; in order that he may not be obliged to examine the latter, in every case in which a classification, already formed, is brought into use. It must be kept in mind, however, that no truly natural system can be established, which does not embrace *all* the peculiarities of internal conformation which anatomical research can discover; since the most important affinities or differences may there be detected, which are not indicated in the slightest degree by external characters.

73. The Animal kingdom was formerly divided into two primary groups; the Vertebrata, possessing a jointed spinal column, within which a principal portion of the nervous system is inclosed; and the Invertebrata, which are destitute of any such structure. The first division included only Mammalia, Birds, Reptiles, and Fishes; the second comprehended all the Insect and Vermiform tribes, the Mollusca or Shellfish, as well as the lowest and simplest of the animal creation.

But it is now generally acknowledged that this method is by no means a natural one, since the Invertebrata contain at least three and perhaps four groups, differing as much from each other as that of Vertebrata does from either of them, and therefore entitled to hold the same rank with the latter. The primary groups or sub-kingdoms, are, therefore, to be regarded as consisting of—I. VERTEBRATA, which are characterised, as before mentioned, by the possession of an internal bony column, composed of jointed pieces or *vertebræ*, within which, or their modifications, the central organs of the nervous system are inclosed; to this column all the other bones in the body are more or less directly attached; and these are covered by soft flesh, which partly consists of the muscles by which they are moved. Of all animals, their structure is most complicated; they all possess the power of active locomotion, and enjoy the senses of taste, smell, sight, and hearing, as well as that of touch. In some the blood is warm, in others cold; but in all it is of a red colour. These characteristic peculiarities undergo various modifications among the lower forms of this group, by which the affinities to the other types are indicated.—II. ANNULOSA or ARTICULATA, animals in which the hard parts or skeleton are external, and formed into jointed rings. This is the character of a large number of classes included in this division, which present, with much difference in complexity, a very general conformity of structure. Thus, from the soft and simple Vermiform tribes, such as the Leech or Earthworm, we pass by almost insensible gradations to the Centipede, and from this, to the highly organised Insects and Crustacea. Although some of the animals contained in this division border upon the lowest of the whole kingdom, yet others are inferior only to the Vertebrata in the complexity of their organisation. A distinct mouth and eyes are almost universally present. The muscles that execute the movements of the body, are attached to the interior of the hard envelope, which, where distinct members are developed, incloses them as well as the trunk. In some of the Annulosa the blood is red, in others it is nearly colourless; and among the Insect tribes there is a power of generating heat, almost as great as among any of the Vertebrata. The locomotive powers are usually very considerable; and the general structure of the body is peculiarly adapted to the predominance of this faculty. There is one group, however, which approaches the Mollusca, in which this tendency is reduced to a subordinate condition, in conformity with other peculiarities of its organisation (§ 92).—III. MOLLUSCA, or Shellfish, with allied species unpossessed of a testaceous covering. This group also includes many animals of high organisation, such as the Cuttle-fish, which approach the Vertebrata very closely in structure and general characters; as well as many whose conformation is very simple. Instead of long jointed bodies equally developed on the two sides, they almost always present an irregular rounded form, with no

distinct members; or, when such are developed, they are but fleshy tentacula (as the *arms* of the Cuttle-fish), or tubercles (as the *foot* of the snail), quite different from the complex jointed limbs of insects or crustacea. In none are the locomotive powers developed to a high degree; many remain affixed during nearly their whole lives to other substances; and in most, the nutritive system appears to predominate above the animal functions. Some have a distinct head, with eyes, ears, and mouth; whilst others are destitute of any organs of special sensation, and the entrance to their alimentary canal is not indicated by its situation on any prominent part of the body.—IV. RADIATA, or radiated animals, a group which formerly included a vast quantity of most heterogeneous materials; uniting the comparatively symmetrical and complex Star-fish and Echini, with those simple beings which form the transition to the vegetable kingdom. The group is now restricted, however, to those animals, which, as the term imports, have their organs arranged in a radiated or star-like form around the orifice to the stomach. Such are Star-fish, the Sea-urchin tribe, and some of the Medusæ or jelly-fish. The locomotive powers are usually inconsiderable, and the organs of sensation indistinct, though rudiments of eyes are suspected to exist; but the nutritive processes appear to be performed with great activity, and some of the softest and most delicate of these animals are known to seize upon and digest the hard bodies of others much higher in organisation. The tribes which have been separated from this group are comprehended in the last division—V. ACRITA, which must be characterised rather by the absence of the peculiarities which separate the other sub-kingdoms, than by any positive distinctions which its members present. There is but little indication amongst the animals which compose it, of any connected nervous system, and none of any special organs of sensation. The tissues are almost homogeneous, and seem equally irritable and contractile in nearly every part; they are whitish and semi-transparent, and appear to be nourished by direct absorption from the surrounding medium, or from the cavity into which food is received, without the intervention of any circulating apparatus consisting of regular vessels; although in some cases there seems to be a motion of fluid through canals excavated in the soft substance of the body. From this simple organisation it results that all the functions are very much blended together; and that, as there is no special organ for each, every part serves a number of distinct purposes to nearly an equal degree. The power of locomotion is in general very slight; and where it is possessed to any great extent, as by the *gemmules* of the Sponges and Polypes (§ 116, 121), it seems difficult to say how far it is to be regarded as voluntary, and how far it is the mere result of peculiarities of organisation, as in plants. A large proportion of this division is entirely fixed during all but the earliest stage of life; and many exhibit so little indi-

cation of sensibility or voluntary power, as to render it doubtful whether they do not belong to the vegetable rather than to the animal kingdom. Just as among the border tribes of the Protophyta, there is frequently great difficulty in determining the precise characters of individuals of this division; for it may be regarded as including a large number of animals in which the characters of higher groups are adumbrated, or, as it were, sketched out; but which have not attained a sufficient degree of general development to deserve a place amongst them.

74. Now it is found that every one of these groups may be characterized by the form and development of its nervous system; and as this has an obvious relation with all the functions, both animal and nutritive, it is probably the best single character which could be adopted, (see CHAP. XVI). Thus, Vertebrated animals have a nervous cord, inclosed in the spinal column which supports the back; and this is dilated by the addition of new parts into the *brain* contained within the cavity of the head, where also it is connected with the organs of special sensation. Hence, they may be termed *spini-cerebrata*. Annulose or Articulated animals, again, present, as the typical form of their nervous system, a double cord studded at intervals with *ganglia* or knots; this runs along the lower or abdominal surface of the body, protected, however, by its general envelope, and is connected with similar ganglia within the head, which are large in proportion to the development of the organs of special sensation, but which never correspond entirely with the brain of vertebrata. In those species in which the locomotive apparatus is most connected with one part of the body, as in insects, the ganglia no longer present their regular disposition through the whole trunk, but are concentrated in its neighbourhood, so that their peculiar arrangement is less evident; but in these, at an early period of life, the typical conformation is witnessed, to express which, the term *diplo-neura* has been applied to this sub-kingdom. In the Mollusca, the nervous system is principally concentrated around the entrance to the alimentary canal, forming a circle of ganglia, through which the œsophagus passes, and which is connected with other ganglia, disposed without symmetry among the viscera, or in the neighbourhood of the organs of locomotion, if such should be specially evolved. In some of the highest of this division, the nervous system approaches very closely in its arrangement to the form it presents in the lowest vertebrata, and receives a corresponding protection by a rudimentary internal skeleton; but, in general, it is more connected with the immediate supply of the nutritive functions, and wants that symmetrical arrangement and close connection with the locomotive organs, which may be regarded as characters of elevation in the nervous system of the Articulata. From the general plan of the distribution of their ganglia, Mollusca have been termed *cyclo-gangliata*. The Radiata present such a form of nervous system as might be expected, when the peculiarity of the

arrangement of their organs is considered. It is composed of a filamentous ring, which surrounds the mouth, and sends off branches to the different divisions of the body; a slight ganglionic enlargement being usually perceptible where these fibres are given off. Hence these animals have been termed *cyclo-neura*. Among the Acrita, no definite or connected nervous system is discoverable, except in those species which border upon the neighbouring divisions. Most naturalists imagine that globules of nervous matter are incorporated with the individual tissues. The probability of this supposition will be hereafter considered (CHAP. XVI). At present, the *classes* or subdivisions of these primary groups will be described with somewhat more of detail.

75. The MAMMALIA, which unquestionably assume the highest rank in the whole animal creation, as well as amongst the vertebrated classes, are particularly distinguished from all others, not only by producing their young alive (which is done by some species much lower in the scale), but by their supporting them by suckling for some time after birth,—whence their name. This, indeed, is the only single obvious, and, at the same time, universal character which is peculiar to them: for though they may be described as warm-blooded animals, breathing air, and having a complete double circulation, this would include Birds also; or if they were characterised as four-legged animals which live on the ground, they would be associated with Reptiles; and if the hair or fur which generally clothes the body be assumed as a distinctive peculiarity, it would scarcely hold good, since it is absent from the surface of such as are covered with scales, like the Armadillo, and something much resembling it is exhibited by the degenerated feathers of some birds which approach nearest in character to the Mammalia. The general structure of this class is sufficiently well known to render it unnecessary to dwell upon it in this place; and it does not come within our purpose to enter into its sub-divisions or orders. To examine the mode in which the typical structure of the group is adapted to all the different conditions in which its members are respectively to exist, tracing the conversion of a terrestrial mammiferous animal into one destined to range among the finny tribes of the ocean, or to skim through the air on wings like a bird, would at any time be a most interesting pursuit. Nor would it less tend to raise our ideas of the Unity of Nature's Design, to see these modifications evidenced in many of the smaller sub-divisions, though not carried out to the same completeness as in the principal orders. Thus, we have not only, in the *Cetacea* or whale tribe, a whole order of mammalia adapted to the conditions in which fishes alone ordinarily exist, and, in the *Cheiroptera* or bat tribe, a similar adaptation to the life of birds; but, among the *Carnivora* we find the seal and its allies, among the *Rodentia* the beaver, among the *Pachydermata* the hippopotamus (and probably a still more remarkable animal, the dinotherium, an extinct species forming a link

between this order and the Cetaeca), and among the *Edentata* the extraordinary ornithorhyncus or duck-billed platypus,—all more or less aquatic in their habits; and, in like manner, we observe the flying lemur among the *Quadrumana*, the flying squirrel among the *Rodentia*, and the flying opossum among the *Marsupialia*,—all of which have, to a certain extent, the power of supporting and moving themselves in the air, by means of expanded membranes connected with their limbs or tails. Well marked as the characters of the mammalia appear to be, they exhibit a very distinct transition to the class of birds, by the order *Monotremata*, one species of which, the ornithorhyncus, has already been mentioned; as well as, in a less degree, by the *Marsupialia*. In the animals of the latter tribe, such as the kangaroo and opossum, the young leave the uterus at a very early period of development, and are conveyed into the *marsupium* or pouch of the mother, where they remain attached to the nipple for a considerable time, scarcely exhibiting signs of sense or motion, and incapable of maintaining a separate existence. In the *Monotremata*, the embryos seem never to acquire the same direct connection with the parent which they possess within the uterus of the higher mammalia, and in this respect they appear to resemble the eggs of birds, though the period and mode of their birth has not yet been ascertained; the mouth is entirely destitute of teeth; and in the ornithorhyncus it is provided with a horny bill, like that of birds; this animal also possesses spurs on its hinder feet, like those of a cock.

76. The class of BIRDS is distinguished by the possession of a complete double circulation and warm blood, at the same time that their generation is oviparous; by their covering of feathers, which, however, sometimes degenerate almost into bristles or quills, like those of the porcupine, or into scales like those of fishes; by the position of their bodies upon two feet only, and the modification of the anterior members for wings, (this, however, being by no means constant); by their want of teeth, whilst the bones of the jaw are covered with a horny bill; and by various other characters of less importance. The senses of sight, smell, and hearing seem to be more acute than those of taste and touch; it is for their locomotive powers, however, that this class is most remarkable. It is pretty certain that some species can fly at the rate of 100 miles an hour, and maintain this velocity for some time; but although the power of flight is that which most evidently distinguishes birds from other Vertebrata, it is by no means possessed to the same degree by all. In the tribe of *Cursores* or runners, for instance, the wings are not sufficiently developed to raise the body from the ground; yet it is believed that they assist, by beating the air, the action of the powerful legs, by which an Ostrich is able to keep pace with a fleet horse. In the *Penguin*, again, the wing resembles in form the fin of a fish, and the feathers assume the appearance of narrow scales lying one

over the other; as instruments of flight they are of course entirely useless; but when the bird is once in the water (which it rarely leaves), the fin-like wings become a pair of powerful oars, capable of propelling the body at a prodigious rate. All the accounts given by navigators favour the belief that the Penguins, however helpless on land, are yet the swiftest family of swimmers in the feathered creation, rivalling the swallows in the rapidity with which they pursue their prey. The modifications which the typical structure of the Bird undergoes to meet the various conditions of its existence, can scarcely be regarded, however, as equally considerable with those presented by the Mammalia; they are principally due to the relative development of the anterior and posterior extremities; and the law of *balancing of organs* (§ 208) is no where better illustrated than in the comparison of the legs and wings of the Ostrich with those of the Swallow. The Ostrich and its allies present many points of transition to the Mammalia, not only in their external covering, but in their internal conformation; some of these will be hereafter noticed. With Reptiles, a class differing from that of Birds in almost all its prominent characters, no animals now living would seem to indicate a connection; but here we have a remarkable instance of the necessity of including extinct forms in our classification, in the fact, that in the fossil genus *Pterodactylus*, there is such a singular union of the characters of the two classes, that much controversy has taken place as to the one in which it should be located. Birds have been called the Insects of Vertebrated classes; and when we come to describe the position of Insects among the Articulata, it will be seen that the expression is not inappropriate.

77. The class of REPTILES, which is next to be considered, presents more diversity of form among its separate orders, than any other among Vertebrata. Nothing would seem more unlike than Tortoises, Lizards, Serpents, and Frogs; yet the differences between them are not in reality so great as to prevent their association into one class, distinguished by the characters which are common to all. Reptiles are cold-blooded animals, having a heart with only three cavities, and an incomplete circulation, (only a portion of the blood transmitted to the body having previously passed through the respiratory organs); they usually breathe, in their adult state, by lungs; though some of them respire by gills in their early condition, and a few retain them during life. This deficiency in the oxygenation of the blood, combined with the slowness and feebleness of the circulation, is connected with general inactivity of the nutritive functions, as well as with obtuseness of sensations and sluggishness of locomotion. It is a curious result of the feeble exercise of these functions, that they may be suspended for a considerable time without apparent injury to the animal; and that parts separated from the body retain, for a long period, the low degree of vitality which they

usually exhibit in connection with it. Although, at present, Reptiles appear to perform a comparatively insignificant part in the economy of Nature, especially in temperate climates, where their numbers are comparatively few and their powers feeble,—we learn from the records of Geology, that there was a period in the earth's history, long antecedent to the creation of Birds and Mammalia, when gigantic animals of this class not only constituted the chief tenants of the earth, but extended their dominion over the waters of the sea. With regard to the external appearance of the Reptiles in general, it may be remarked, that their low degree of animal heat requires no fur or feathers to retain it; and that those which are most injuriously affected by a high external temperature, namely the Frog tribe, have a soft naked skin, by transpiration from which the body may be kept cool, and the noxious influence resisted. Where a scaly covering exists, as in the Tortoises, Lizards, and most Serpents, its individual parts are to be regarded as appendages of the same kind with the horns, hair, or feathers of the higher classes, being formed by a corresponding set of organs.

78. The order *Chelonia*, or Turtle tribe, is characterised by the absence of teeth, the horny covering of the jaws which resembles that of birds, the possession of four feet, and the inclosure of the body in a shell-like covering. The want of teeth, claws, or other weapons of offence, is thus compensated by their means of passive resistance. The shell, as it is commonly called, is composed of two distinct portions; the upper one, which is termed the *carapace*, is usually more or less arched, and is composed of a bony expansion of the ribs, which are consolidated into a firm structure, and covered with the horny plates that constitute the true shell; whilst the lower plate, termed the *plastron*, is nothing but a peculiar development of the sternum or breast-bone, which, instead of being prolonged forwards into a *keel*, to give attachment to large muscles as in birds, is extended laterally for the protection of the subjacent parts. This order passes, by a very remarkable species, the *Emys serpentina* (alligator-tortoise, or snapping-turtle), into that of the *Sauria* or Lizards, which is characterised by its elongated body covered with scales, the possession of teeth, and the presence of legs, of which four is the typical number. Whilst all the Chelonia are herbivorous, many of this order derive their support from the animal kingdom alone, and their carnivorous tendency is indicated by the character of their teeth; some of the largest among the extinct species, however, appear to have been vegetable feeders, possessing teeth more adapted for grinding and bruising than for cutting and tearing. Most of them are modified for progression on land; though the crocodiles chiefly inhabit the water, for propulsion through which, their fin-like tail is adapted: whilst the *Draco volans*, a harmless and beautiful little inhabitant of tropical woods, and the only living representative of the fabulous Dragon, passes

part of its time in fluttering from branch to branch by means of its wing-like appendages (§ 194); and from the skeleton of the *Pterodactylus*, its powers of flight must be regarded as having been considerable (§ 193). This extinct animal would appear, from the conformation of its teeth, to have been insectivorous; and thus it seems to have represented, both in character and functions, the class of Birds, which was not then called into existence. Two other remarkable extinct genera belong to this order, which exhibit peculiarities of organisation indicative of affinities to distant groups. The *Ichthyosaurus* immediately connects fishes with lizards, as its name imports; presenting the head and teeth of the latter, combined with the vertebral column of the former; as well as a union of other organs, apparently heterogeneous, but without doubt perfectly adapted to the conditions of its dwelling. The *Plesiosaurus* appears to have been a still more singular animal, uniting to the head of a lizard and teeth of a crocodile, a long neck like the body of a serpent; a trunk and tail having the proportions of an ordinary quadruped; the paddles of a whale; and the ribs of a chameleon, the peculiarity in form of which seems connected with very great distensibility of the lungs.

79. The transition of form from the Saurian tribes to the next order, that of Serpents, is made out by very evident links. Although Lizards have usually four legs, some species have only two; and the two which are deficient, are the anterior in one species, and the posterior in another. In the *Anguis fragilis* or slow-worm, no extremities appear outwardly, but they may be demonstrated by careful preparation of the skeleton; and amongst the undoubted members of the order *Ophidia* or serpents, rudiments of extremities may be detected in several instances. Although apparently so different from the Saurian reptiles, Serpents are to be distinguished by little but the absence of extremities; as in the possession of teeth, and the scaly covering of their bodies, they completely correspond with them. The elongated form of their bodies reminds us of the vermiform tribes among the Annulosa, which they may be considered as representing among the Vertebrata; and they correspond with them in a very curious particular, which exists in no other tribe of Vertebrata, namely, the periodical exuviation of the skin. It would scarcely be supposed that a link could be found which should connect the Ophidia with the frog tribe; yet this exists in the *Cœcilia* (naked serpent), an animal destitute of a scaly covering, having a soft skin like that of the Batrachia, and resembling the latter in many points of internal organisation. The *Batrachia* themselves are among the most remarkable tribes of animals in the whole kingdom, however despised the members of it may be. Besides the naked skin, which is the principal character that distinguishes them in the adult form from other reptiles, and the imperfect separation of the heart into three cavities, they possess another peculiarity, which is regarded by many naturalists as sufficient to constitute them a distinct

class rather than order, namely, the change of form or *metamorphosis* which they undergo, in their growth from the young to the adult state. All the animals belonging to this order, such as the frog, toad, water-newt, and some others less known but still more remarkable, resemble fishes in their tadpole or imperfect state, but afterwards assume more or less of the reptile form; they thus act as a connecting link of a very peculiar kind between the two classes. The tadpole, when it has just emerged from the egg, is essentially a fish; it is deficient in members, moving solely by its tail; it breathes by gills, and all its organs are adapted to aquatic respiration; its brain and nervous system, its circulating and digestive apparatus, are all those of a fish. As the animal grows, the body increases in size, while the tail remains stationary; the legs are put forth, the hind pair appearing first; the gills are superseded in function by the lungs; the tail becomes rudimentary; the gills disappear; and the animal quits the water in the form of a frog, breathing air, and depending for locomotion on its extremities alone. Some of this order, however, which undergo a complete metamorphosis, remain aquatic, such as the common Salamander or water-newt; these, however, do not breathe by gills in the adult state, but take air into the lungs at the surface of the water, which they are therefore occasionally obliged to visit. There is a period in the development of the tadpole, at which there is a kind of balancing between the organs which are disappearing, and those which are being evolved; when the lungs and gills exist simultaneously, and the legs as well as the tail are employed for progression. This state is *transitory* in the common tadpole, and only exists for a short time; but in some animals of this order it remains *permanent*, their development, as it were, being checked; so that they never assume the complete reptile form, but retain the gills along with imperfect lungs, and the tail united with short extremites. Of these curious animals more will be said hereafter (§ 409). A curious link between the Batrachia and the Chelonia has recently been discovered in South America, being nothing less than a frog furnished with a carapace and plastron; by this, the *circularity* of the group of Reptiles is completely established. The Batrachia have no weapons, either of offence or defence; taken as an order, they are certainly as harmless to man as any tribe of animals; and though the forms of many of the species offend against our notions of beauty, and their love-songs give them the character of "horrible musicians," there is certainly nothing to justify the aversion and prejudice with which they are ordinarily regarded.

80. It may not be inappropriate to stop here for an instant, to enquire how far the existence of a metamorphosis can be regarded as a character sufficient to establish this or any other group into a distinct class, if the general structure of the adult do not warrant the distinction. It will hereafter be stated (§ 202) as a general law of the organised

creation, that in the evolution of each of the individual organs of the higher tribes, a series of conditions is passed through, which bear an evident analogy with those that are permanent in the lower parts of the scale. In the human embryo, for instance, the first appearance of the nervous system resembles that which exists in the lower vermiform tribes; and at a subsequent period, the brain presents the successive characters peculiar to the fish, reptile, bird, and mammiferous animal, in their adult states. The heart and circulating system, the respiratory system, and many others, will be shown to undergo a corresponding series of changes. The later portions of these occur in the embryo of the Marsupialia after it has quitted the uterus, but whilst still remaining attached to the exterior of the parent; and in the egg of birds, the whole development of the embryo takes place independently of the parent, subject only to the warmth with which it may be artificially supplied. Now the difference between the metamorphosis of the Batrachia, and the changes which occur in the embryos of Birds and Mammalia, consists in this:—that in the latter case, the life of the fœtus being maintained by nutriment either continually supplied by the parent, or stored up in the ovum, there is no necessity for that harmony between the corresponding states of its different organs, which is essential to a being that is to maintain an independent existence; and the development of each, therefore, goes on without reference to the corresponding state of the others. In the tadpole of the frog, or the larva of the insect, on the other hand, there *is* that harmony; the embryo does not receive sufficient nutriment from its parent stored up within the egg, to enable it to arrive at its full development before quitting its envelope; it comes forth, therefore, in a state which, as regards its ultimate condition, is imperfect; but in this state it is enabled to maintain its existence, by procuring and assimilating its own food, since its organs are functionally adapted to each other, though universally presenting, for a time, the characters of the class below. The changes which the tadpole undergoes in its conversion to a frog, or the larva in its metamorphosis to the perfect insect, are not different *in kind* from those which all animals of complex organisation present at some period of their existence, although peculiar in their combination and *synchronism;* they cannot, therefore, be regarded, in a classification based upon philosophical principles, as sufficient of themselves to characterise a class.

81. The last class of the vertebrata is that of FISHES, which are cold-blooded animals, inhabiting the water, and breathing by gills during the whole of life; possessing but two cavities in the heart, having the body covered with cartilaginous or bony scales, and the extremities metamorphosed into expanded fins. Their whole structure is adapted for progression in water, and the movements of propulsion are principally executed by the lateral action of the spine, whilst the fins are used for

the purpose of balancing the body, and of modifying its direction. The peculiar construction of the spinal column endows it with great flexibility, at the expense, however, of strength; but the latter is not required in beings whose bodies are universally buoyed up by the surrounding element. The tail is flattened vertically, and increased power is given to the stroke of the body by the prolongation of the spinous processes of the vertebral column into the dorsal fin; fishes are thus remarkably distinguished from the cetacea (their representatives among air-breathing animals), the flattening of whose tail is horizontal, for the purpose of bringing the body to the surface for respiration by means of its vertical stroke. The pectoral fins of fish answer to the arms of man, and the ventral fins, which are connected with the pelvic bones, to his legs; besides their uses in steering, they assist in raising the fish vertically through the water; and in species whose habits frequently require this kind of motion, the ventral fins are brought much forwards, and are even situated anteriorly to the pectoral. As we have seen birds modified to inhabit the water, so do we find fish adapted in some degree to rise in the air; the flying-fish being enabled, by means of the stroke of its expanded fins on the surface of the water, to skim over it for a considerable distance, though not to execute a sustained flight in a medium of such rarity contrasted with its usual element. Fishes are subdivided into the osseous and cartilaginous; the former being possessed of a bony skeleton, whilst the framework of the latter is comparatively soft. Although many cartilaginous fishes present a high degree of organisation, and even produce their young alive, (hatching the eggs within the oviduct), others exhibit the simplest forms of vertebrated structure, and seem to pass towards both the Mollusca and the Annulosa. Thus, we find species, especially among the extinct groups, in which the whole body is enveloped in a covering of dense bony scales, and the internal cartilaginous skeleton is scarcely more developed than that which exists as a protection to the nervous system of the higher Cephalopodes; and to this class another transition is exhibited in the tentacular appendages prolonged from the mouth of some of the cyclostome fishes, which evidently represent the arms that, among the cuttle-fish, are developed to so great an extent, and constitute the principal organs of locomotion. There are other species, again, which in the entire absence of members, the non development of any hard protection to the nervous system, the uniform size of the latter from one extremity of the column to the other, the general softness of their tissues, and the flexibility of the body, bear a very close resemblance to the Vermiform tribes; such are the lamprey and myxine (hag), in the former of which the spinal column is a simple cartilaginous tube, and in the latter the nervous cord has only a membranous envelope, and no eyes or distinct jaws are developed. There are also some species of fishes which exhibit a distinct transition in the structure of their teeth, verte-

bral column, and respiratory organs, to the lizard tribes; of these the only living representative is the *Lepidosteus* or bony pike of the North American lakes; but, from the researches of Agassiz, it is probable that they were formerly very numerous.

82. The difference which has been already pointed out between the internal skeleton of the VERTEBRATA, and the hard external tegument of the ARTICULATA, is a very remarkable one, and deserves further notice. In the latter group we often observe the trunk presenting exactly the same divisions into head, thorax, and abdomen, as in the former; and where distinct articulated members exist, the joints of their horny or calcareous sheath correspond in number and situation with those of the higher vertebrated tribes, the grand difference being that in the former case they are all *external*, and in the latter *internal*. We shall enquire, then, in what this difference consists in a philosophical point of view. The *skeleton* of an animal is that harder portion of its tissues, which is destined to afford protection to the more delicate and important organs, and support to the soft parts of the body in general; under this definition, therefore, we may include, not only the *bony* apparatus of the Vertebrata, but also the dense scaly covering by which some even of these are protected externally, and which sometimes (especially among extinct races of fishes) appears of more importance to the support and protection of the animal, than its soft internal skeleton. The same definition will include the calcareous tegument of the crab, the horny casing of the insect, the more massive shell of the oyster, and even the stony stem of the coral. In forming our estimate of the relation of these structures to the systems with which they are respectively connected, we must take into account the whole conformation of the animal, and not hastily decide that parts are to be regarded as dissimilar, which, though apparently diverse in form and character, are constructed by modifications of the same parts, and fulfil the same office in the economy of the animal. In the Vertebrata, the integrity of the brain and spinal marrow, the centres of nervous energy, is so essential to the life of the system, that the preservation of these organs is the chief object of the skeleton. These important parts are therefore inclosed in a bony case, formed of several portions united by ligaments, so as to combine flexibility with strength. As appendages to this *neuro-skeleton*, as it may be termed, we find a set of bones giving firmness to the extremities, which are organised for locomotion in various ways, and in the higher Vertebrata are adapted for other purposes also; but these cannot be regarded as essential parts of the skeleton, since we find them absent in the whole of the order Ophidia, rudimentary in many of the Lizards which approach nearest to them, and in Fishes giving up their peculiar function to the tail. In some of the latter class, in which the internal skeleton affords but slight protection to the nervous system, from its softness and want of resisting power, the support required by the

more delicate organs of the body is given by a peculiar modification of the skin, which is beset with plates of bone and enamel, forming a *dermo-skeleton*. Among the Invertebrata, the neuro-skeleton is entirely absent, except in a few of the highest species, where it exists in a rudimentary state (§ 96), the dermo-skeleton being highly developed and supplying its place. The nervous system in these animals is less concentrated than in the Vertebrata; there are many centres of power instead of one. It does not, therefore, require such a specific protection, since injury to one part does not necessarily involve the destruction of the animal; and the skeleton is consequently adapted, by its external position, to the protection of the whole of the soft tissues of the body, and not to that of the nervous system alone. The high development of the locomotive powers in the Articulata requires that this dermo-skeleton should be adapted by its numerous joints to their free exercise, equally with the neuro-skeleton of the Vertebrata; and it is this adaptation, (by the division of the covering of the body into distinct rings or segments, and its prolongation into articulated members,) that constitutes the difference between the light but firm tegument of the Annulose tribes, and the more dense and massive protection of the Mollusca, which is in reality formed, like the other, by a secretion from the membrane that answers to the skin.

83. This leads us to advert to the very important difference in character between the skeleton of the Vertebrata and that of the Invertebrated classes. The bone which constitutes the former is a true living structure, traversed by blood-vessels, absorbents, and nerves; and is subject to that continual renovation by which all the living tissues of the animal body are characterised. The dermo-skeleton of the latter, on the other hand, when once formed, undergoes no further change: it is adapted to the increasing size of the body, either by being periodically cast and renewed by those animals whose entire surface it covers, as by *Crustacea;* or by addition made to its edges, where these are free, and do not entirely enclose the body, as in the *Mollusca;* or by similar additions made to the jointed edges of its individual parts, as in that curious class, the *Cirrhopoda*, which represent the Mollusca among the Articulated tribes. In all these cases, the skeleton is to be regarded as, when once formed, independent of the nutritive system, or *extra-vascular*, like the nails, horns, hair, scales, or feathers, of Vertebrata, which are all distinct rudimentary forms of the dermo-skeleton; and the latter is carried to its highest development where no more completely organised internal fabric is yet evolved.*

* Besides the peculiarities common to the Articulated classes, which have been formerly mentioned, there is one which deserves especial notice, when they are compared with Vertebrata. The double nervous cord of the Articulata has been stated (§ 74) to run along the *abdominal* surface of the animal, and would thus appear to hold an opposite position in the body from that which the corresponding part of the nervous system possesses in the Vertebrata. But, when closely examined, it is found that this inversion is common to other parts of the fabric, the intestine being situated in the back, the respiratory organs hanging from the abdo-

84. It is not very easy to say which class of the ARTICULATA is to be regarded as the highest; some possessing marks of superiority in one system, and some in another. Insects, for example, breath air, and have a very complex organisation; but their nervous system never presents itself in the same concentrated form as that of the CRUSTACEA, which may be briefly described as annulose animals, resembling insects in their general form, but possessing four or more pairs of legs, usually encased in a jointed calcareous shell, and breathing by gills instead of air-passages; they have compound eyes like those of insects, and are furnished with two pairs of antennæ. The crab, lobster, and cray-fish are well-known illustrations of this class, which was formerly included by Linnæus, with that of Arachnida, under the general division of Insects; but there are many other forms less familiar, which serve to connect it with the neighbouring groups. The dense envelope of these animals would interpose too great a resistance to the increase of the body, were not the means provided for its periodical renewal. The *exuviation*, or throwing-off the old shell, is preceded by evident illness on the part of the animal, which retires to its hiding place at the time. The soft skin is soon covered with a sort of mucous exudation, which contains a large quantity of calcareous matter, and speedily hardens; and it would seem that the earthy deposit in the stomach, commonly termed *crabs-eyes*, disappears at this period, being, in fact, a kind of reservoir of lime, stored up against the time of want. In the process of exuviation it is not uncommon for the animal to lose part of a claw, which is speedily replaced by a new one from the broken joint. The second articulation from the body is the part at which the fracture most frequently occurs, and is probably the only one from which the new growth can issue; since if the claw be broken off below that point, the animal itself effects the removal of the upper portion, either simply casting it off by violent muscular contraction,† or striking it against some hard body. The Crustacea in general, at the time of their first emersion from the egg, differ considerably from their adult form, especially in the number of their legs; for there is a remarkable power of modification in the anterior pairs, which are sometimes true legs, sometimes changed into claws, and sometimes converted into jaws; and they are found in some species in every stage of transition between these extreme forms. The changes which they undergo during their development can hardly be regarded as amounting to a metamorphosis like that of insects, although

men, &c.; so that a lobster placed upon its back will exhibit a conformity in the situation of all the essential organs with the Vertebrata. This view is confirmed by the fact that the yolk-bag, to which the animal is attached in the egg, opens into the intestine by an umbilicus situated on the dorsal surface, and not on the abdomen, as in Vertebrata (§ 537); as well as by the relative position of the motor and sensory columns of the nervous system (§ 570).

† Some specimens of the *Gecarcinus* or land crab in the Zoological Gardens were observed to throw off their smaller legs with great ease, in order to escape from any one who injudiciously took them up by those members.

some naturalists have described them as such. The members of the different orders of Crustacea have, however, a much greater resemblance to one another in their early states than subsequently; for it is only in the progress of their growth that the characters which distinguish the genera and species evolve themselves; and hence there has been much confusion amongst naturalists regarding them. In the lower orders especially, there is frequently a kind of premature liberation of the embryo from the egg, so that the animal has subsequently to undergo a part of the same series of changes, which the higher species pass through before quitting the ovum. This subject is one of the most curious in the physiology of these animals, but it has not yet been fully investigated. The highest order, that of Decapodes, which contains the Lobster, Crab, &c. indicates a transition towards both the Arachnida, and the Myriapoda; for whilst the short-tailed, soft-bodied crabs look like enormous aquatic spiders, some of the long-tailed lobster tribe conduct us, through an order in which the segments of the body are still more distinct and equal, (as in the common wood-louse), to the centipedes. Others, again, indicate an evident affinity with the Cirrhopoda (§ 92), especially to the transitory form of the latter; and there are species but little elevated above the higher Entozoa (§ 94).

85. The next class, termed ARACHNIDA from the general resemblance of its members to Spiders, also differs from the true Insects by possessing more than six legs; eight being here the usual number. The head, like that of many of the Crustacea which approach them in form, is united with the thorax; but is destitute of antennæ. The eyes of this class are peculiar, as not possessing the compound structure which characterises those of Insects and Crustacea, but as resembling the simpler though more perfect organs of vision in the Vertebrata. The respiration is also peculiar, being performed by organs which are neither lungs nor gills, but present analogies to both (§ 402); they are, however, adapted for breathing air, most of this class being inhabitants of the land. Many interesting animals are included in it; such as the *Spiders*, the structure and employment of whose spinning organs are so curious; the *Scorpions*, remarkable for their enormous claws, which resemble so much those of the Crustacea, and for their long jointed tail terminated by a sting; and the *Acari* or mites, which are either parasitic upon other animals, or exist upon decaying organised matter.* The legs of the Arachnida are

* The Spiders are probably the most remarkable among the whole animal kingdom for the variety of their means of obtaining their prey. Some of them bore habitations for themselves in wood, earth, or any other penetrable masses; lining them with a silken tapestry of most beautiful texture, which is adapted to resist humidity; and guarding their entrances by trap-doors, furnished with a hinge, so accurately fitted as not to be perceptible externally, and closing of themselves when the animal has passed through. Within these tubes, the little inhabitants lie in wait for their prey, dart out upon it when near, and drag it back to their dens to devour it at leisure. Others, again, form large nets of the most beautiful

renewed after injury, in the same manner as those of the Crustacea. The links which connect them with that class have already been noticed; those which form the transition to the Insect races are less evident; although the affinity which exists between the parasitic Acari and some not very dissimilar forms amongst Insects, cannot be very distant.

86. Although inferior in certain individual points of structure to the classes already described, that of INSECTS would certainly appear to present, in the most elevated degree, the combination of those peculiarities which are characteristic of the Articulata in general, and should therefore be regarded as its typical group. Its predominance in number of species above all others is not a little remarkable; according to Mr. Swainson the probable estimate would reach 550,000, whilst the total remaining species of the animal kingdom at present existing on the globe do not amount to 30,000, or scarcely one-twentieth of the whole. The name of this class is derived from the well marked division into head, thorax, and abdomen which its members usually present. It is characterised by the possession of six legs, compound eyes, antennæ, and wings, in the perfect state; and also by the existence of a metamorphosis through two distinct forms, previous to the attainment of that which ultimately characterises it. The caterpillar or *larva* which afterwards changes to a beetle, a butterfly, or a wasp, bears no resemblance whatever to its perfect or *imago* form, and is in fact allied in almost every particular of its conformation to a class far beneath, namely, the ANNELIDA; so that a naturalist, who should not be aware of their ulterior metamorphosis, would unquestionably associate the larvæ of many Insects with that class. After what has been already said (§ 80) of the nature of this change in a philosophical point of view, the application of the same principles to the present case can be a matter of no difficulty. The alteration in the whole character of the animal is no less evident in the metamorphosis of Insects than in that of the Batrachia. In the larva condition, its whole energies seem concentrated upon the nutritive functions; and the increase in the weight of the body is very rapid; whilst in the perfect insect, the reproductive system is called into exercise, the body no longer increases in size, and the evolution of an active locomotive apparatus induces an entire change in its habits. Although nearly the whole of this class are produced in the state of eggs like other Annulosa, a few are brought forth alive, the egg having been hatched within the body of the parent. One peculiarity

texture and regular conformation, near which they lie hid, until warned of the neighbourhood of their game by a line passing from the centre of the web to their place of concealment, from which they dart forth, and do not hesitate to attack the largest insect entangled in their toils. The *hunting spiders*, which are unprovided with such means, are possessed of peculiar agility, and spring upon their prey like tigers, seldom missing their aim.

attending the eggs of Insects is, that they frequently increase in size after being laid, probably by imbibing moisture, like plants, from the surrounding medium.

87. The *Larva* when it first emerges, bear but a very small proportion to its subsequent bulk. That of the silkworm weighs, when hatched, $\frac{1}{100}$ of a grain; previously to its first metamorphosis it increases to ninety-five grains, or 9,500 times its original weight. During its growth, it throws off its skin several times, like the Crustacea; and the rudiments of the organs to be subsequently evolved are gradually formed within. The body of the larva is divided into thirteen segments or rings, of which the anterior one constitutes the head; the rest are nearly similar to one another, and, in general, each is furnished with a pair of short legs. There is obviously but little necessity for the development of the locomotive powers in this condition, since the food is always vegetable, and the egg is deposited by the parent in such a situation that a supply shall be within reach of its progeny as soon as required. There is a remarkable correspondence between the different kinds of caterpillars and the different orders of Annelida. Some are, like the leech, destitute of eyes and members, and move by suckers at the ends of the body; others have the legs moderately developed and possess eyes; others are aquatic and breathe by gills; and we may regard the *caddis-worm*, which constructs a casing for itself by glueing together bits of stick or straw, and grains of sand or gravel, as the analogue of the Tubicolæ (§ 91), which form a similar artificial protection to their soft elongated bodies. In many insects, however, the larvæ differ but little from the perfect state, except in the absence of wings, their development having proceeded much further before they quitted the ovum. The larva first changes itself into the state of *Pupa* or chrysalis; previously to which it often spins a silky bag or cocoon, in which it encloses itself. The pupæ of the different orders of insects differ much in form and in degree of torpor. Some have the whole body inclosed in a horny case without vestige of members, and are totally inactive, except when disturbed; whilst others retain their legs, and possess their locomotive powers almost undiminished, scarcely seeming, in fact, to pass into the pupa state at all. The metamorphosis is said in the latter case to be *incomplete*, not because the ultimate form of the insect is less perfect, but because the change is less distinct; those which exhibit all the phases described, in their most evident form, being said to undergo a *complete* metamorphosis.

88. In the *Imago* or perfect state, the Insect still retains the thirteen segments which are characteristic of the group; they are, however, no longer similar, but combined into separate divisions. The *head*, which is regarded as the first segment, is quite distinct from the body; the *thorax* contains the three succeeding rings closely united together, and these always retain their legs, with the addition of the wings, which are

developed from the third and fourth segments; the *abdomen* consists of the nine remaining rings, more or less consolidated, and entirely destitute of legs. The especial function of the perfect insect is the continuance of the species; and the wings enable it to seek its mate, and to obtain a situation fit for the deposition of its eggs. Many insects, as the silkworm-moth, do not eat after emerging from the pupa state, and die as soon as they have fulfilled this object; and in few is there any marked increase in bulk during this stage of their existence. It has been well observed that there is a beautiful correspondence between the metamorphosis of insects, and the development of flowers. Every species of plant exhibits itself, in the course of the year, in different states. First are seen the succulent stems adorned with the young foliage; next emerge the flower buds; then the calyx opens, and permits the tender and lovely blossoms to expand. The insects destined to feed upon each plant must be simultaneous in their development. If the butterfly came forth before there were any flowers, she would in vain search for the nectar that forms her food; and if the caterpillar was hatched after the leaves had begun to wither, it could not exercise its functions in devouring them. The eggs of many insects are laid in the autumn, and remain unchanged during the winter; their development being excited, like the evolution of plants, by the genial warmth of the spring. Others, again, pass the chrysalis part of their existence at the same season, and come forth as perfect insects early in the ensuing year. The senses of the Imago seem usually acute, especially those of vision and smell, although the special organ for the latter has not been detected. There is a difference of opinion with regard to their hearing, some entomologists believing that they are entirely deaf, whilst others attribute this function to their *antennæ* or feelers. That the latter are delicate organs of touch, can scarcely be doubted by those who have watched the employment of them; and that, by their use, individuals have the power of communicating with each other, is regarded as probable by those who have observed the habits of insects living in societies, as the Bee and Ant.

89. The characters which have been mentioned as peculiar to this class undergo considerable modifications in some of its border groups. Thus, the *Podura* or spring-tail belongs to an order which does not undergo any metamorphosis, and is deficient in wings; some of its species approach the Myriapoda in structure and habits. The *Pediculus* (louse) and similar parasitic insects may, in like manner, be considered as forming an *osculant* or connecting group; being allied in many respects to the parasitic *Acari* among the Arachnida: so that the place of one curious species, the *Nycteribia* (bat-louse) is doubtful, Latreille having placed it among Insects, and Dr. Leach considering it as belonging to the Acari. The true Insects are usually divided primarily into

two extensive groups, the *Haustellata* and the *Mandibulata;* the former obtaining their food by suction through a *haustellium* or proboscis, and the latter biting it by their *mandibles* or jaws. The latter division, however, presents many approaches to the former; some of its members, as the bee, not using the jaws for mastication, but collecting the food by the tongue, which is so elongated as to serve almost as a proboscis.*

90. We must now quit this most important and extensive group, and pass on to the next class, the MYRIAPODA, towards which some links of transition have been pointed out, both among Crustacea and Insects. In fact, some species among the former, in which the segments are nearly equal, and the number of legs great and uncertain, pass almost insensibly into this class. There is here no division of the trunk into thorax and abdomen; and the head is not always very distinctly separated from it. The segments of the body are numerous, and nearly equal, each possessing a pair of legs. The head is furnished with antennæ and simple eyes; and, in the poisonous species, the second pair of legs is formed in the shape of a claw, through an aperture in the point of which, the poison is made to issue from its reservoir. In this class there is sometimes a kind of metamorphosis, the animal acquiring several additional segments and legs after quitting the egg. One of the orders is harmless; the other contains the Centipede, which is the best known illustration of the class. The largest specimens brought to this country are a foot long; though some are described as attaining the length of a yard.

91. The ANNELIDA present us with a still further simplifieation in

* From the rank and importance of this class in the animal kingdom, and from the differences of structure and constitution presented by its various forms, it seems desirable to indicate its principal subdivisions, to which reference will be occasionally made hereafter. That of Mr. Kirby, being founded on adult structure, and not on the nature and degree of the metamorphosis, appears to possess the best title to be here adopted. Excluding some orders of minor importance, the principal ones may be thus arranged, each being regarded as holding in *its* sub-class, a corresponding position with the parallel one in the other :—

HAUSTELLATA.		MANDIBULATA.	
1. *Diptera*	(Gnat, Gad-fly, &c.)	5. *Hymenoptera*	(Bee, Wasp, Ant)
2. *Lepidoptera*	(Butterflies, Moths)	6. *Neuroptera*	(Dragon-fly, Ephemera)
3 *Homoptera*	(Cicada, Lantern-fly)	7. *Orthoptera*	(Grasshopper, Locust)
4. *Hemiptera*	(Boat-fly, Bug)	8. *Coleoptera*	(Beetles).

These orders are all named according to the character of their wings. In the 1st, only one pair of these organs is developed; but the rudiments of the other are discernible. In the 2nd, the wings, which are membranous, are overspread with a downy covering, which consists of delicate scales of the most elaborate beauty. In the 3rd, the wings are all nearly alike, but their texture is somewhat coriaceous or horny. In the 4th, the anterior or upper pair resembles horn or leather at the base, but is membranous near the tip. In the 5th and 6th, both pairs are completely membranous; the veins which support them being, in the former, disposed like the ramifications of blood-vessels, and, in the latter, crossing each other nearly at right angles. In the 7th, the upper pair is somewhat coriaceous, the lower membranous. And in the 8th, the upper wings being entirely coriaceous or horny, and not being used in flight, are termed *elytra* or wing-cases; beneath these, the second pair, which are membranous, and frequently of considerable size, are folded transversely as well as longitudinally, so that, when the elytra are closed, they are completely excluded from view.

the form of the body, the segments being usually less distinct, and the head not separated from the trunk; we observe also the gradual disappearance of members,—from the highest species which approach the Myriapoda in their possession of jointed appendages, down to those simple worms in which the body is entirely smooth. Thus, the *Nereis* or sea-centipede, and its allies, have one or two pairs of long, jointed, bristle-like appendages to each of their segments, which appear to serve as legs when the animal creeps over the surface of the bed of the ocean; whilst the respiratory tufts (§ 392), by their movements, serve as its organs of propulsion in water. Some of these present affinities not only to the Myriapoda, but to the Isopod Crustacea. Another order, the *Tubicolæ*, which includes the Sabellæ, Serpulæ, &c., has a long naked body indistinctly divided into segments, and its respiratory and locomotive appendages collected together at the head; the remainder being enclosed in a tube which the animal either excavates from hard sand, or constructs by the agglutination of bits of sand, shells, &c., or forms, like the Mollusca, by a calcareous exudation from its body. In fact, until the peculiar characteristics of the Articulata were understood, the Serpula was placed among Mollusca. In still lower grades, such as the earth-worm, we find locomotion performed almost entirely by the body, but assisted by bristles on the surface, of which four belong to each segment. In the lowest order, of which the leech is an example, we find no trace whatever of appendages; the division into segments is scarcely perceptible, and locomotion is entirely performed by the body, which is furnished with suckers at each end. At the same time that the body and appendages are thus gradually simplified, there is a progressive diminution in the peculiarities of the head; that of the Nereidans being distinct, with eyes, jointed organs like antennæ, and a proboscis armed with jaws: while in the leech it is nothing more than the entrance to the intestinal canal, not being in the least separated from the body, and being unprovided with regular jaws, eyes, or other organs of special sensation; the sensibility being here diffused over the whole surface.

92. The class CIRRHOPODA (Barnacles) was long regarded as appertaining to the Mollusca, on account of the shell-like covering of the body, its fixed condition, the absence of a distinct head, and other peculiarities; it was, however, removed to the Articulata on account of the *diplo-neurose* character of the nervous system; and all the knowledge which has been acquired since that time of its structure and development, confirms the propriety of this alteration. The body presents some indication of division into segments, and possesses six pairs of jointed arms; but the head is indistinctly defined, and has neither eyes nor tentacula. Their conformation is symmetrical, or nearly so; and thus differs from that of all but the highest Mollusca (§ 138). The most curious point in their organisation is the structure of the shell; this is composed of several distinct pieces, each having the power of increase at its edges, so as to

enlarge the capacity of the whole; and it is thus adapted to the increasing size of the animal, without that periodic exuviation which is common to the hard envelopes of the Articulata in general, but which would not have suited the Molluscous character of these animals. Of the chemical constitution of these it may be remarked, that whilst the shells of the Crustacea are composed of a mixture of phosphate and carbonate of lime, and the hard envelopes of Insects of a peculiar animal principle termed *chitine* (combined with phosphate of lime where any calcareous matter exists), the shells of the Cirrhopoda consist, like those of Molluscous animals, almost entirely of carbonate of lime, and possess a more distinct crystalline structure than those of crabs. Each division of the shell has a groove along its edges, into which the mantle (as it is called in the Mollusca, answering to the skin of other animals,) is prolonged, for the purpose of depositing additional matter when required. One division of this class, the *Balani* (acorn-shells), have the bases of their pyramidal shells fixed upon rocks or other large masses of matter; whilst the *Lepades* (Barnacles) attach themselves to floating bodies by a membranous tube, sometimes of considerable length. They appear to obtain their food by the whirlpool which they create by the motion of their jointed arms and of the *cilia* (§ 110) with which they are fringed. The changes which the animals of this class undergo during the progress of their development, have recently been made a peculiar object of enquiry; and the very unexpected result has been, that the young animals on their liberation from the egg are found to possess a form much more analogous to that of the lower crustacea, than that which they are ultimately to assume. Four stages have been described by Burmeister as being presented by the animal subsequently to its emersion from the egg. In the first, it is possessed of no hard covering, has two long antennæ, and three pairs of arms tipped with bristles, by which it freely moves through the water; and it is believed to be furnished with eyes. At a subsequent time, the animal fixes itself by its antennæ, and the shell, of leathery consistence, begins to be formed in one piece at the back of the body; and at this period the eyes are very distinct and brilliant. In the third stage, the divisions of the shell begin to appear, and it more completely encloses the animal, at the same time becoming more solid by the deposition of calcareous matter. Soon after the animal completely fixes itself, the old integuments, together with the antennæ and eyes, are thrown off. The fourth stage is that in which the development is completed. Although the ciliated arms of adult Cirrhopoda evidently possess great sensibility to touch, no organs of special sensation can be detected in them. Some observers have remarked, however, that they shrink from a strong light brought to shine upon them suddenly; and Dr. Coldstream has noticed the closure of the opercula of the Balani, on the movement of the hand or other part of the body in their vicinity.

93. Besides these classes, which are all that are included by many naturalists in this sub-kingdom, there are two others which present its characters in a less degree, and the situation of which may be regarded as uncertain. One of these classes is that of ROTIFERA, the complex structure of the animals composing which, was long overlooked, owing to the minuteness of their size. The class is a very circumscribed one, including only the *wheel-animalcules*, and their allies, which have been separated from the common Infusoria, on account of their highly developed nervous and muscular systems, as well as of the complexity of their masticating and digestive apparatus. These beautiful little animals derive their name from the circular arrangement of their vibratile cilia (§ 110), which appear when in motion like revolving wheels, and by the action of which they not only move from place to place, but, when they have fixed themselves by the sucker at one extremity, create a vortex in the surrounding water, which brings the food to their mouths, and probably aërates their circulating fluid. Some species, when their wheels are closed up, present an appearance not very dissimilar to that of the leech, the body being then elongated, having some trace of segments, and furnished with a sucker at each end; whilst others approach the simple crustacea, both in form and structure. The common *Vorticella rotatoria* (Fig. 77) has a wheel on each side of its prolonged head, and two spots on the latter, believed to be eyes. Within the body is a very curious masticating apparatus, which is seen to move with great energy and regularity when the wheels are in action. The nervous cord is very distinct, being usually double above, where it surrounds the œsophagus, and single below; and it possesses ganglia, particularly at its upper part, where the principal movements of the body are executed. In proportion to the complexity of their organisation, this class is endowed with remarkable tenacity of life, many of its members being capable of revival after entire desiccation.*

* This fact has been doubted by some high authorities, especially by Ehrenberg, who states that he has never succeeded in producing this revival. The following statement of my own experience on the subject may not therefore be undesirable. In the summer of 1835, I placed a dozen specimens of the *Vorticella rotatoria* in a drop of water, on a slip of glass, and allowed the water to dry up, which it did speedily, the weather being hot. On the next day I examined the glass under the microscope, and observed the remains of the animals coiled up into circles, a form which they not unfrequently assume when alive, but so perfectly dry that they would have splintered in pieces if touched with the point of a needle. I then covered them with another drop of water; and in a few minutes ten of them revived, and speedily began to execute all their regular movements with energy and activity. After remaining alive for a few hours, I again allowed the water which covered them to dry up, and renewed it on the following day with the same result. This process I repeated six times; on each occasion one or two of the animals did not recover, but two survived to the last; and with these I should have experimented again, had I not accidentally lost them. It is possible that the species on which Ehrenberg, and other foreign naturalists have experimented, may not be the same as that which I and other English observers have used. This tenacity of life appears peculiarly adapted to the habits of the animal, which prefers shallow waters that are liable to be occasionally dried up.

94. The second of the classes alluded to is that of the ENTOZOA or parasitic worms; this, however, includes animals as various in structure as the different vertebrated animals inhabiting the same country; and although it has been made a subject of distinct study by many naturalists, there can be little doubt that it should be divided into at least two principal groups, the situation of which in the animal scale is widely different. One of these contains those species which are possessed of a distinct intestinal tube, with an orifice at each end, and of a nervous system more or less developed. These may perhaps be considered as deserving a place among the Articulata, especially as many of them show traces not only of a division of the body itself into segments, but also of the evolution of articulated members and of organs of special sensation. This is the case among the very curious *Lerneæ* recently described particularly by Nordnann, as attaching themselves to the eyes of fishes; they approach the lower Crustacea in complexity of structure, possessing not only distinct jaws, but rudimentary antennæ, and having the body divided into segments, of which three form a thorax separate from the head and abdomen, and of which each is furnished with a pair of rudimentary legs. Others, again, belonging to this division, bear more resemblance to the lower Annelida; such are the *Filaria* or Guinea-worm, which burrows beneath the skin in tropical regions, and the *Ascaris lumbricoides* or Round-worm of the intestines. These last are included in the division *Nematoidea* of Rudolphi, the *Vers cavitaires* of Cuvier, the *Cœlelmintha* of Mr. Owen. If they be admitted as a distinct class into the sub-kingdom Articulata, they certainly connect it very closely with that of Acrita; the latter including, amongst its classes, the other division of Entozoa, in which no distinct traces of a nervous system or of members are to be detected, and in which the intestinal canal, where it exists, is merely hollowed out of the general soft tissue of the body.

95. It is the necessary result of any natural system of classification, that in pursuing one type of organisation through all the forms in which it manifests itself, we are led from the highest and most complicated, to creatures of such simplicity as to be, in reality, of a lower rank than others belonging to a group which, considered as a whole, is below that in which they are included. Even amongst the Vertebrated classes, there are, as we have seen (§ 81), some species which must be regarded as inferior in general character to the more elevated among the Articulata, and which actually present the greatest affinity with members of the lower classes of the latter. The typical character of the Vertebrata is unquestionably much higher than that of the Articulata, and yet it may be presented in such a degraded form as scarcely to be recognisable. In the same manner, although the active locomotive powers and acute sensations of the Articulata in general, would seem to entitle them to a place in the animal series above that assigned to the Mollusca, a large proportion

of the beings included in the latter group must be regarded as much more elevated than the simpler vermiform tribes we have been last considering, amongst which the typical characters of the sub-kingdom are presented in their least evident condition. The range of animal forms comprehended in the sub-kingdom Mollusca, is so great, that it would be difficult to include them by any character common to all. The highest class approaches Fishes in many points of its organisation; and in the lowest, we not only lose many of the peculiarities of the division, but we find a number of distinct individuals associating to form a compound animal, as is the case with many among the Acrita (§ 104). In all the Mollusca, the body itself is of soft consistence, as its name imports, and is enclosed in a soft elastic skin, lined with muscular fibres, which is termed the *mantle.* This skin is frequently not applied closely to the body, but forms a membranous bag, having apertures for the admission of the surrounding water to the mouth and respiratory organs, which are situated within it, as well as for its subsequent ejection, and also for the protusion of the head and foot where these organs exist; sometimes these apertures are for particular purposes extended into proboscis-like tubes (Fig. 83). It is from the surface of the mantle that the calcareous matter is exuded that forms the shell (where the animal is furnished with this protection), which possesses the same relation to it that the casing of the crustacea holds in reference to their true skin; it occupies the place of the *rete-mucosum* or coloured layer in the skin of higher animals, and is covered in its natural state by an *epidermis* analogous to the scarf-skin of man, which is, however, generally removed in preserved specimens, since it impairs the beauty of their exterior. The Mollusca possess, in general, a complicated digestive and circulating apparatus; but they are very imperfectly provided with the organs of sensation and voluntary motion. The greater number, indeed, are formed for an existence as completely stationary as that of the Zoophytes, which grow like a tree from a fixed base; and are dependent for their nourishment on the supplies of food casually brought within their reach by the waves and currents of the ocean. As among the Cirrhopoda, however, even the species which are afterwards to become attached, swim about freely in their immature state. The shell is most solid and massive in those species which lead an inactive life; and is usually very light and thin, or altogether deficient, in those whose powers of locomotion are greater. As it does not inclose the whole body, there is no occasion for the exuviation which takes place in the covering of the Crustacea, or for the division into segments and addition to the edges of each, which are necessary to meet the wants of the Cirrhopoda; and accordingly we find that the size of the shell is progressively increased by deposits of new matter from the mantle, lining its interior and extending beyond the margin (where the mantle is usually thickened into a glandular structure),—this extension

taking place whenever the wants of the animal require such an addition to its covering.

96. Among the CEPHALOPODA or Cuttle-fish tribe (so named on account of the position of the feet around the head), we find not only links of connection with Fishes, but also some curious analogies with more remote groups. Thus, the animals of this class possess a beak composed of two firm horny mandibles, like those of the parrot in form; and are furnished with a muscular stomach like the gizzard of birds. The beak encloses a large fleshy tongue; and in the head are also situated well developed eyes, a distinct organ of hearing, and what is probably a rudimentary form of the organ of smell. There are two distinct groups in this class, which are particularised by the number of their gills; but their general structure is so different as to require separate notice. In the highest of these divisions, which contains the common *Sepia* (Cuttle-fish), *Loligo* (Calamary), &c., there is (with the exception of the Argonaut or Paper Nautilus) no external shell enclosing the body; although a rudiment of it, which is frequently quite horny from deficiency in calcareous matter, exists within the folds of the mantle on the back. Where this is the case, the nervous system, which possesses in these animals a very elevated character, would be almost entirely destitute of protection, were it not partly enveloped by cartilaginous plates, which may be regarded as the first indication of the neuro-skeleton, manifested where the dermo-skeleton is least developed. All the Cephalopoda which are destitute of an external shell are provided, in the ink-bag, with a remarkable means of escape from their enemies; the dark pigment contained in it being ejected upon the slightest alarm, and by diffusing itself rapidly through the water, serving to conceal them effectually. The locomotive apparatus of this division consists not only of the arms (eight or ten in number) disposed round the head, but, among the long slender-bodied cuttle-fish in which these arms are least developed, of fins attached to the sides of the body (Fig. 78, *a*, *a*), and furnished with cartilaginous supports, which seem to be the rudiments of the more perfect members of fishes; by these they are able not only to propel themselves through the water, but even, it is believed, to spring out of it like the flying-fish. In the common *Octopus* or Poulp the feet are connected for some distance round the mouth by membranes and muscles which form a kind of circular fin: whilst in the Argonaut, the first pair of arms is provided with two expanded membranes, which the animal has been supposed to erect into the air as sails; and this use of them has been a subject of poetic imagery in all ages. According to Mr. Owen, however, as the same appendages are possessed by two other species, of which neither inhabits a shell, and in which the expanded membranes could not be used "to waft the animal along the surface of the ocean, as has been said and sung of the Argonaut from Aristotle to

Cuvier, from Callimachus to Byron," the physiologist is compelled to abandon the idea as altogether a poetic fiction.

97. The second division of the Cephalopoda contains those which inhabit a shell, and which, from their comparative inactivity, and their general inferiority of development, as well as from particular points in their organisation, may be regarded as connecting the group already described with the inferior Mollusca. Instead of the few long powerful arms which the Cuttle-fish exhibits, the true *Nautilus* and its allies have the mouth surrounded with very numerous short and comparatively feeble tentacula, which resemble those of many Gasteropoda. It is thus seen that the *feet* or *arms* by which this class is characterised, have really no analogy to corresponding parts in Vertebrata, but are simply an excesssively developed form of a structure which is common to other tribes of Mollusca, and of which traces may be found in fishes (§ 81). The organs of sensation in this division appear less acute than those of the *naked* Cephalopoda (those unprovided with an external shell); and that of hearing seems altogether absent. Like other *testaceous* Mollusca, the animals of this division possess no organs of rapid locomotion. The structure of their shell is, however, peculiarly interesting. In all species at present known, it is spiral, and divided by transverse *septa* or partitions into chambers, in the largest and external one of which, the body is enveloped (Fig. 79). When its bulk has increased so as to be too great for the chamber, the animal forms a new one by prolonging the mouth of the shell; and at the same time, it throws a septum across the portion it has quitted. It still retains a communication, however, with the empty chambers by means of a membranous tube, termed the *siphuncle*, *a*, *a*, which passes through all the septa, and is capable of considerable distension.* A spiral chambered shell, although forming the prominent character of this group, is not, however, altogether restricted to it. For even the flat bone of the Cuttle-fish exhibits traces of a corresponding structure; and in the *Spirula*, a shell very similar to that of the Nautilus is enveloped within the body, the animal itself resembling a Sepia. And, among the extinct species, although affinity of structure undoubtedly places the *Ammonites* and *Nautilites* in the same position with the

* By this structure, the animal appears to be enabled to rise or fall in the water at pleasure. It would seem that the specific gravity of the body and shell are so nicely adapted to that of their element, that a very little difference will cause them to swim or sink. When the animal is at the surface and wishes to sink, it forces into the siphuncle a quantity of water previously contained in the pericardium or bag inclosing the heart; the distension of the siphuncle compresses the air in the chambers, and the bulk of the exterior of the body being thereby diminished, its specific gravity is increased and it consequently sinks. When it wishes to rise, it has only to withdraw the pressure from the pericardium; the elasticity of the air in the chambers forces the water back from the siphuncle into the external cavity, and thus by increasing its total bulk renders its specific gravity again less than that of the water. This account, which has been recently given by Dr. Buckland in his Bridgwater treatise, is the only satisfactory explanation yet offered of the use of this apparatus.

existing Nautilus, the *Belemnite*, which possessed a conical chambered shell, must certainly be associated with the Sepia, since the remains of the ink-bag (which is possessed by none but *naked* Cephalopoda) are found in connection with it. A very interesting point in the structure of the *naked* Cephalopoda, is the organisation of the *suckers*, with which their arms are copiously provided; these are adapted to lay firm hold of any object to which they are applied, by the creation of a vacuum beneath. The food of most of this class appears to consist of Crustacea, animals which might have been supposed peculiarly difficult for them to master; but they probably overcome their prey by winding their arms around their claws and legs, whose motion they prevent by their suckers, and then tear off the shell with their firm horny mandibles.

98. The PTEROPODA form a small class of Mollusca, of which little need be said; they derive their name from the fin-like expansions of the mantle on each side of their bodies, on the surface of which the gills are situated; but these fins are never supported by rays. The head is provided with tentacula, but seldom with eyes. The body is frequently unprotected; and where a shell exists it is very delicate and almost transparent. Their habits are active, and they are often found swimming in myriads near the calm surface of the ocean. "Their delicate structure" says Dr. Grant "is ill adapted to encounter an agitated sea, or the dangers of a rocky or shallow shore; and it is only in the vast and deep ocean that their elegant forms and colours and their graceful motions delight the mariner's eye, when the glassy surface of the still sea reflects the rays of the setting sun." One of the most common species of this class is the little *clio borealis* (Fig. 80), which exists in such multitudes in the arctic latitudes as to constitute the chief food of the whale. The shells of two species afford indications of a transition towards the Cephalapoda; one resembling in its straight conical form the belemnite and many other extinct genera of that class, and the other having a partially formed chamber at the lower closed extremity; and similar evidence is afforded by their internal structure.

99. Of the large number of species included in the class GASTEROPODA (so named from the situation of the muscular disk upon which the animal creeps, in the neighbourhood of the digestive organs), some are entirely naked or destitute of shells; others possess a small shell, covering one part of the body or imbedded in the back, as in the slug; whilst others are almost entirely enveloped in shells, varying in form from the simple cone of the Limpet, to the convoluted spiral of the Snail, and the still more complex fabric of the Murex. It is perhaps amongst the tribes of this class that we find the characters of the Mollusca in general most prominently displayed; the high development of the nutritive apparatus, combined with sluggish powers of locomotion; and the consequent deficiency of that resemblance between the two halves of the body which is essential in an animal adapted to rapid movement, and which, in the

higher Mollusca, has triumphed over that unequal disposition of their organs which is common to all the rest of the group (§ 138). In all the more perfect forms of this class (which are usually carnivorous), the head and eyes are distinctly retained; but in the naked species (which are mostly vegetable feeders), these organs are not evolved. Many curious transitions might be pointed out between different groups, indicated by the form of the shell. Thus the passage from the simple cone of the Patella (limpet) to the spiral of the snail, is evident in such as the *Pileopsis* where the point of the cone is prolonged and somewhat convoluted (Fig. 81); and the gradations are so close as to make it difficult to draw a distinct line of separation. From the spiral we may return again to the long straight form of the shell, by the *Scalaria preciosa* in which the turns of the spire touch each other only by the ribs; and by the *Vermetus* (Fig. 82), and *Magilus*, in which the commencement only of the shell possesses a spiral form, the remainder being prolonged into a straight tube, so as to have led to the opinion of their affinity with the *Serpulæ*, which among the Annelides form a shell by no means dissimilar. The *Magilus* is an animal which fixes itself on coral beds, and as their thickness increases, it is obliged to prolong its shell to their surface; sometimes to such an extent, that the animal leaves altogether the spiral portion first formed, which it fills up, more or less completely, by a deposition of solid calcareous matter, and entirely resides in the tube. The *Vermetus*, which is similarly circumstanced, throws a septum across the part which it has quitted, closely resembling that of the chambered shells among the Cephalopoda, and, in fact, differing only by the want of a siphuncle. Instances of a similar tendency occur among other Mollusca (§ 102). The shell, it must be recollected, is simply an exudation from the skin; and the characters of the animal alone can be regarded in a classification strictly natural. In the naked species of Gasteropoda, especially those which inhabit the land, the skin is thick and dense, so as to afford a certain degree of protection; in others, which have no shell externally, a small one is imbedded within their substance; and amongst those which have an external shell, every variety is presented in the degree in which it is capable of affording protection to the entire animal. Where the head and respiratory organs, which are usually situated near the entrance to the shell, are capable of being entirely drawn within it, there is not unfrequently a tubular prolongation of the mantle, adapted to a channel in the *columella* or central pillar, round which the spire turns, for the purpose of conveying water to these organs without the necessity for their quitting the shell.*

* The term *mantle* being frequently employed, as it might appear, synonymously with *skin*, it may be well to explain again that it is a portion of the skin concerned in the secretion of the shell, differing from the rest in its thick and glandular character; and sometimes it is prolonged considerably farther than any of the organs which it encloses, either, as in the present instance, to form a tube, or to increase the surface of the shell.

100. The shell in all cases is enlarged by additions to its interior surface, a new layer being thrown out by the mantle, which projects beyond the former ones, and thus increases both the length of the spire or cone, and the diameter of its outlet. In terrestrial shells, when full growth has been attained, a rim or margin is formed around the aperture, which serves to strengthen the whole fabric; while in the marine species, which attain to much larger dimensions, the growth is effected at distinct periods, each of which is indicated by a well defined margin. This margin is sometimes fringed with spines, as in the *Murex*, formed by prolongations of the mantle; and the dissimilar number of these spines has led to the establishment of many distinct species, which, when the habits of the animal were better known, have proved to be but different forms of the same. For it now appears that the animal has not only the power of forming new spines, but of removing old ones, especially such as would interfere with the continued growth of the shell. How the absorption of shelly matter from their base, which causes them to drop off, is effected, is still unexplained; various analogous phenomena may be witnessed among other species, portions of the shell first formed being wholly or partly removed. Sometimes the walls of the older portion are thinned for the purpose of lightening the shell, and the same object seems to be attained by other inhabitants of spiral shells in a different manner; these withdraw their bodies from the highest part of the cone, throw a partition across the cavity, and then allow the point (which, not being internally supported, is brittle, and appears to have been purposely thinned,) to be broken off, leaving the shell *decollated* as it is termed.* It must be borne in mind, however, that the changes thus effected in the shell are not the consequence of any *interstitial* absorption, such as takes place in the osseous structures of Vertebrata; but result from the same kind of power of *superficial* absorption, as appears to be exercised by many Gasteropoda upon calcareous rocks, which they perforate for their habitations, as well as upon the substance of their own shells. It is believed by many that this power consists in the secretion of an acid which decomposes the substance; and by others that it is the result of an electrical action which separates the components in another method.

101. Several of the aquatic species of this class form not merely a spiral shell, but an accurately fitted cover to its mouth, so attached to the body that when the latter is entirely withdrawn, the *operculum*, as it is called, completely encloses it. Sometimes this is horny, but not unfrequently calcareous; and occasionally it bears so large a proportion to the shell as almost to appear like a second valve, such as is characteristic of the Conchifera. Some of the land species also possess

* Mr. Stutchbury informs me that he has seen the Bulimus forcibly strike the apex of its shell against a stone, for the purpose of decollating itself.

an operculum; but in general they are destitute of it, and form during hybernation a temporary closure to the mouth of the shell by a viscid secretion, which becomes hard and includes a bubble of air; behind this a second and even a third similar partition are occasionally found, as in the common snail. In a marine species allied to the snails *(Janthina)*, the matter secreted by the mantle, which in other cases forms either a permanent operculum or a temporary partition, appears destined for a very different purpose. When the sea is calm, according to the statement of Bosc, these beautiful violet-snails may be seen collected in large bands, swimming over the surface by means of a floating apparatus consisting of air vessels of unequal size, produced by a membranous secretion from the foot. When the sea is rough, the animal absorbs the air from its vesicles, changes the direction of its foot, contracts its body, and lets itself sink. It does the same when in danger from any enemy; and like the naked Cuttle-fish (which the peculiar thinness of the shell causes it to resemble in the want of other protection), colours the water by the emission of a blue fluid, which serves to conceal it.

102. The next class to be considered is that of CONCHIFERA, which includes all the Mollusca whose shell is composed of two principal pieces, or those usually termed *bivalve*. It is not upon the structure of the shells, however, that the division is formed; but upon that of the animals contained in them, which differs essentially from that of the individuals composing the class last described. They have been termed *Acephalous* Mollusca, from the circumstance of the head being undistinguished from the rest of the body, in any way but by the presence of the mouth; for no special organs of sensation are possessed by them, except perhaps those of taste. It would seem, however, that even in these, there is some sensibility to light; and in a few species, which are endowed with more than the usual locomotive powers of the class, some traces of eyes may be discovered. The *Pectens*, for example, are free swimmers, and from their rapid and desultory motions have been termed the butterflies of the ocean; the manner in which these motions are performed, especially on the approach of danger, indicates the possession of a sense analogous, at least, to that of ordinary vision. In general, however, the Conchifera are peculiarly inactive; a large proportion of them remain fixed to the spots they have originally selected; either immediately, by the attachment of the shell itself,—or by the intervention of the *byssus*, a cord formed by a series of brown silken threads, loosely intertwined, connecting the foot of the animal, by which it is spun, with rocks or other secure places. The two valves of which the shell is composed, are connected by a hinge formed of teeth that lock into one another; and this joint is sometimes very perfect, and so peculiar in its character, that even when the shells are dry, it allows free motion of the valves without permitting them to be separated. In general, however, the

retention of the valves in apposition to each other, is due to a ligament connected to the hinge in such a manner, that its elasticity keeps the valves somewhat apart, unless counteracted by the action of the muscle in the interior of the shell, which draws them together. This is a very beautiful provision for the performance of the animal functions without difficulty or effort; for when undisturbed, the ligament keeps the valves open; but when danger is apprehended, or circumstances require it, the adductor muscle contracts, overcomes the resistance of the hinge, and shuts the valves close, until they may be opened with safety. One of the earliest signs of the loss of vitality in Conchifera, is the unusually wide gaping of the shell, which arises from the continuance of the elasticity of the ligament, (which does not disappear as long as its structure is undecomposed), unbalanced by the vital contractility of the muscle. The valves are formed and increased by successive layers secreted from the mantle, just as among the Gasteropoda; but here we find them attaining much greater size and solidity. It has been observed, however, that the quantity of calcareous matter thus deposited as a protection to the animal, varies with the character of the element it inhabits; thus, a species which in calm water forms but a light delicate shell, will sometimes produce one of a solid and massive character, if its habitation be among the agitated waves of the ocean. A curious provision exists among Conchifera, for adapting the capacity of the shell to the size of the body, which reminds us of the facts already mentioned regarding other Mollusca (§ 97 and 99). An oyster kept without food, will frequently expend its last energies in secreting a new pearly layer, at a distance from the old internal surface of the concave valve, corresponding to the diminution of bulk it has experienced during its fast. The Spondylus repeatedly does the same thing, so that its concave valve, when cut across, exhibits a large number of regular chambers, which bear an evident analogy with those of the Nautilus; the object here, however, as in the Magilus, is to prevent the animal from being imbedded by the growth of the coral to which its shell is attached.

103. Although usually so sluggish, many of the Conchifera possess considerable muscular power, which is manifested in the force with which they draw together the valves, and sometimes in the powerful action of the foot. Thus, the common cockle can take considerable leaps, by suddenly extending this organ, which was previously bent at an acute angle; and Mr. Stutchbury has mentioned to me, that the first specimen of Trigonia which he discovered on the coast of New South Wales, having been placed in the stern of the boat from which he was dredging, leapt over the gunwale, a height of about six inches, into the sea. This feat argues a power of vision on the part of the animal. Bosc states that the animals of the genus Venus may be seen in calm weather sailing

on the surface of the waters, using one of their valves as a boat, and the other as a sail. No special organs of locomotion, however, seem to be evolved in this or other cases where the animal is unattached; the action of the foot appearing to produce the more rapid and violent movements; while the constant *ingestion* on one side, and *ejection* on the other, of the currents of water which are to pass over the respiratory organs, and to supply the digestive system, would seem to produce the slower and more equable motions. This passage of water occasionally takes place by means of two restricted openings in the sac of the mantle, which are even prolonged into tubes or siphons; in many species, however, the divisions of the mantle lining the two valves are not connected at their edges to any great extent, so that the water has free entrance to the cavity within the shell. To this class belong the greater part of the boring-shells, which have so remarkable a power of excavating rocks, timber, &c.; the means by which they produce the effect are still obscure, some considering it to be by mechanical, and some by chemical action. The tendency among some of the Gasteropoda to the formation of an enlarged operculum like a second valve, has already been noticed; the transition would likewise be established by the genus *Orbicula*, which has one valve formed like the shell of the Patella; so that a Norwegian species in which the lower valve is particularly thin, and unattached by a hinge to the upper, has been described as belonging to the last order. The passage to the lower group of Mollusca, the Tunicata, is so direct, that Lamarck and other naturalists have united the two classes under the general title of Acephala.

104. The TUNICATA, or naked Acephala, seem to establish the transition between the Mollusca and Acrita, by connecting the class last described with the Polypiferous tribes,—not only through their individual structure, but in the instances they present of the association of a number of single and independent beings to form a compound animal. The Tunicata are of soft consistence, unpossessed of a shell, but having their organs enclosed in a stiff leathery envelope or *mantle*, which has two openings, one for the ingestion of water to the mouth and gills, the other for its ejection. In the general structure of their organs, the higher species, which are usually free, approach very closely to the Conchifera; whilst the simple ones, which are attached to rocks, &c., border as closely upon the Polypes. The external tunic possesses considerable contractility, which appears to be under the control of the animal; since, when alarmed, it ejects the water contained in its cavity with considerable force. The *Ascidia* (Fig. 83) is a species of this class which occurs in the northern seas and attaches itself singly to rocks; but the more remarkable are the *Pyrosoma* and *Salpe* of warmer latitudes, which usually exist as aggregate animals. The single animal has a form somewhat elongated, the oral aperture being at one end, and the anal at the

other, instead of being in proximity as in the Aseidia. A large number assoeiate themselves into the form of a hollow eylinder (Fig. 84), eaeh individual having the oral opening eonneeted with the central passage, and the other situated externally. In the Atlantie speeies, this tube is usually about five inches long; and in the Mediterranean it sometimes attains the length of fourteen. These animals are highly phosphorie, and when floating ou the surfaee of the oeean, exhibit not only a dazzling light, but the most brilliant sueeession of colours. They do not appear to possess any independent power of loeomotion, exeept that conferred by the direetion of the eurrent of water, whieh is always entering one extremity of the tube, and, after passing through the bodies of the little animals whieh compose it, is ejeeted externally and somewhat in the opposite direetion. Although elosely attaehed to one another, these associated animals are eapable of being separated by a smart shoek applied to the sides of the vessel in whieh they are swimming; and it appears that at a eertain period of their existenee, this separation takes plaee spontaneously, their assoeiation being only maintained during their young state, when, perhaps, it is required for their mutual support and proteetion from injury. A similar phenomenon has been already notieed in the vegetable kingdom (§ 69).

105. We now arrive at the sub-kingdom Radiata, whieh, although deeidedly inferior to the Mollusea in general organisation, eannot be regarded as sueceeding them in the deseending seale, sinee it rather possesses affinities with the Artieulata. The peeuliar eharaeter of the animals eomposing this division of the Animal ereation, consists, as has been mentioned, in the *radiated* disposition of their parts round a common eentre; and these parts are usually but repetitions of one another, so that one or more may be removed without injury to the funetions of the remainder. Sueh beings form the natural links of transition from those more highly elaborated struetures, in whieh every organ is of a different eharaeter, and dependent for the due performanee of its functions upon the integrity of the rest,—to those more simple animals, in whieh the different parts are so eompletely repetitions of one another, as not only to be eapable of removal without injury to the welfare of the system at large, but even to possess the power of maintaining an independent existenee.*

* In the first part of his General Outline of the Animal Kingdom, just published, Professor Jones adopts the designation *Nematoneura* proposed by Mr. Owen for this division, as eharacterising the filamentous eondition of its nervous system, opposed on one side to the Acrita, in whieh none can be deteeted, and on the other to the higher groups in which ganglia are discernible. In this group of Nematoneura, Prof. Jones associates with the Echinodermata, the Cavitary Entozoa and Epizoa (§ 94) and the Rotifera (§ 93) already described among the Articulata, as well as the Cilated Polypes, which will be presently mentioned (§ 117); and he places the Acalephæ among the *Acrita*, with the Polygastrica (§ 113), Sterelmintha (§ 111), inferior Polypes (§ 115), and Sponges (§ 121). This classification is

106. The first and most highly organised class of Radiated animals is that of ECHINODERMATA (prickle-skinned), which derives its name from the spiny integument of some of its species, and comprehends those well-known animals, the *Echinus* (sea-urchin), *Asterias* (star-fish), as well as many others. The Echinus, one of its most perfect forms, is nearly globular in shape: and the shell, which is composed principally of carbonate of lime cemented by animal matter, is made up of a number of polygonal plates, which are susceptible of receiving addition at their edges, and thus of keeping pace with the growth of the animal. It is beautiful to observe how completely this structure is adapted to its wants; for as it cannot get quit of its envelope periodically like the crab, or add to its edges like the Mollusca, it is manifest that the animal would speedily outgrow its habitation, were not some means provided for the continued extension of the latter. In this provision there is a manifest resemblance to the means by which the Cirrhopoda add to the capacity of their shell; and, indeed, there is so much correspondence in various particulars between these two groups, that they cannot be considered as very widely separated, although manifestly belonging to different divisions of the animal kingdom. The plates composing the shell of the Echinus are of two kinds (Fig. 85). The larger or *tubercular* plates, are thickly studded on the outside with little hemispherical protuberances, on which the hollow extremities of the spines work, in the manner of a ball and socket joint. The small or *ambulacral* plates have no tubercles, but an immense number of minute holes, through which the animal has the power of putting forth a series of tubes terminated by suckers, which are of great use to it in walking or seizing its prey. These tubes are formed of very delicate membrane lined by muscular fibres longitudinally disposed. When the animal wishes to move forwards, it prolongs them by injecting them with water from its interior cavity; it then attaches the suckers at their extremity to some fixed object; and, by the contraction of the muscle, shortens the tube, and draws the body in the desired direction.

founded entirely upon the presence or supposed absence of a nervous system; and the author cannot help thinking that this, being but a *single* character, must lead to an artificial system of classification if followed alone. In the higher animals, the conformation of the nervous system is so intimately related to that of the whole fabric, that the one necessarily implies the other. But in these lowest classes, the functions of organic life predominate so much over the animal faculties, that the structure upon which the latter are dependent is often obscure. The division Nematoneura, as above specified, contains animals differing from one another in almost every character but the filamentous appearance of the nervous cords; and many of its members would be with difficulty excluded by any definition from the Articulata. It appears to him that the Radiated type of structure is as well marked, and as deserving of a separate rank, as the Molluscous or Articulated; and that if each division be made to include the lowest forms in which its general type of structure is discernible, but few will remain to be associated in the lowest and therefore most heterogeneous of the whole. Thus, the Articulata might perhaps not unfairly embrace nearly all of the Entozoa; the Mollusca, in like manner, might include the Ascidiform Polypes (§ 117); and among the Radiata might be placed not only the Acalephæ, but the Asteroid Polypes (§ 119).

The spines are also capable of being slowly moved at the will of the animal, by means of the system of contractile fibres involved in the skin which covers their bases. In the higher Echinodermata, the intestinal canal has two distinct orifices, which in the Echinus are at opposite sides of the shell; and in the Spatangus and other inferior species, they are nearer each other; whilst the Asterias possesses but one opening, which serves both for the ingestion of food into the stomach, and for the expulsion of the fæcal portions. In the Echinus, the oral orifice is guarded by a very beautiful and complex apparatus of teeth, which is moved by powerful muscles. The food of these animals, consisting of small shell-fish and crustacea, is brought to the mouth by means of the tubular feet; these, having once gained an attachment to the prey by means of the sucker at their extremities, do not quit their hold until it is conveyed to the mouth. From the sluggish habits of the Echinus and the alertness of the motions of the animals which form its nutriment, it would appear difficult for it to seize upon them; but when once they allow themselves to be touched by one of the suckers of their enemy, they are soon seized by a great number of others, and speedily reduced to a pulp in the powerful grinding machine to the action of which they are subjected. In the Spatangus, on the other hand, the dental apparatus is absent; and the stomach is filled with sand, from which the animal appears to remove the nutritive particles mixed with it (§ 240).

107. The different species of this class present a very gradual and curious transition in form, of which the leading types, represented in Fig. 86, may here be noticed. From the almost globular *Echinus*, in which the two orifices of the alimentary canal are opposite one another, we may pass to the flattened *Spatangus*, where traces of a pentagonal figure appear, and in which the intestinal tube terminates nearer the mouth. Thence we are led by the *Clypeaster* and *Scutella*, which are flattened and pentagonal, to the common *Asterias*, in which there is a central body with five or more arms, and a single orifice only to the stomach. Amidst all this change of form, it is curious to observe how the relative situation of the ambulacral plates remains the same. In the Echinus, all the vital organs are concentrated, as it were, into one mass; in the Asterias they are distributed through the arms; but in some of the lower forms of the class, we find them again withdrawn to the centre, that the arms may undergo an extraordinary multiplication and subdivision. Thus, in the *Euryale* and *Comatula*, the arms are much increased in number, and give off branches which ramify and subdivide into minute filaments. Closely connected with this part of the class is the remarkable family of *Crinöidea*, whose fossil remains are so abundant in the older formations, and which have been supposed to be at present entirely extinct. Some small specimens of *Pentacrinus*, are, however, occasionally found in the Bay of Cork; and a larger and very beautiful

species has recently been brought from the West Indies.* These animals strongly resemble a Comatula, placed on a long jointed footstalk, which is attached to the bottom of the sea; and it has recently been stated that the *Pentacrinus europæus* (Fig. 87) is the young of a species of Comatula, which is attached during its early life, and afterwards swims about freely. We shall find that from some of the most ramifying forms of Pentacrinus, the transition is not difficult to the Coralline Polypes; and the Echinoderma are connected to the Articulata, not only by the Balani (acorn-shells) among the Cirrhopoda, but by two peculiar forms presented in their own class, the *Holothuria* and *Siponculus;* in these the tegument is not calcareous but leathery, and the body is elongated instead of being extended radially, so that the Siponculus might really be taken for a vermiform animal (Fig. 88).

108. The ACALEPHÆ (sea-nettles) are among the softest-bodied of animals, seeming to melt away entirely when taken out of the water. They are composed of a soft gelatinous structure without any hard support, except in a few instances. The common *Medusa* or jelly-fish (Fig. 89) is a familiar example of the class. It possesses a radiated form, having a large mushroom-shaped disc, which contains the digestive organs, with various filamentary appendages or tentacula, depending from it. These seem to be constructed somewhat on the plan of the feet of the Echinoderma, being tubular, furnished with suckers, and connected with the internal cavity, from which they are injected with fluid when their prolongation is required. The general mass of the disc is cellular, uniform, and very soft; the quantity of solid matter in it is very small, a Medusa, which when taken out of the water weighs fifty ounces, being reduced when dry to five or six grains. Some traces of muscular structure may, however, be observed in the tegumentary membrane, especially round its margin; and by the contraction of these, the movements of the mantle are produced which propel the animal through the water; other species, however, have different means of locomotion. The *Beroe* (Fig. 90) swims by means of the *cilia* (§ 110) with which it arms are fringed. The little *Velella* possesses a cartilaginous skeleton, formed of a vertical and a horizontal plate; the body of the animal is placed beneath the former, while the latter acts as a sail, being exposed to the action of the gentle breeze, when the animal floats on the surface of the sea in calm weather. Some species of this group are very abundant in the arctic regions, and form an important article of food to the whale. The *Physalia* (Portuguese man-of-war) is very common in tropical seas; it is furnished with an air bladder of an oval shape placed at the upper part of the body; and also with a membrane of a beautiful purple colour, which acts as a sail, like the crest of the Velella. These animals are met with in great numbers in the

* Of this, two very splendid specimens, one of them the most perfect known to exist, are contained in the Museum of the Bristol Institution.

Atlantic ocean, and more especially in its warmest regions and at a considerable distance from land. The following animated account of the Medusæ has been given by M. Peron: "Among the animals of this family, we find the most important functions of life performed in bodies, which offer to the eye little more than a mass of jelly. They grow frequently to a large size, so as to measure several feet in diameter; and yet we cannot always determine what are their organs of nutrition. They move with rapidity, and continue their motions for a long time; and yet we cannot always satisfactorily demonstrate their muscular system. Their secretions are frequently very abundant; and yet the secreting organs remain to be discovered. They seem too weak to seize any vigorous animal, and yet fishes are sometimes their prey. Their delicate stomachs appear to be wholly incapable of acting upon such food, and yet it is digested within a very short time. Most of them shine by night with great brilliancy; and yet we know little or nothing of the agent which produces so remarkable an effect, or of the organs by which it is elaborated. And lastly, many of them sting the hand that touches them; but how, or by what means they do so, still remains a mystery." It will be seen, therefore, that the peculiar nature of their tissues, the singular arrangements of their organs, and the anomalies in their functions present as many objects of interesting enquiry to the physiologist, as the wonderful variety and striking elegance of their forms, and their splendid colouring exhibit to the admiration of the naturalist. Some among the Acalephæ exhibit a decided tendency towards the character of the Mollusca, whilst the greater number are evidently radiate in their structure; the *Actinia* (Sea-anemone), which has by some naturalists been placed in this group, must be regarded as rather belonging to the Polypifera (§ 120), but it forms a close link of connection between them.

109. These two classes are the only ones in which the radiated type of conformation distinctly exists; we have now to examine those lowest and most dissimilar forms of animal structure, in which no definite character can be traced as universally pervading the group in which they are associated, but which appear like sketches or adumbrations of fabrics higher and more remote from each other. They agree, however, in the general simplicity of their structure, and in the absence of any decided characters which would justify their assignment to other divisions of the animal kingdom. The tissues of the Acrita all present a still more homogeneous appearance, than in the simplest of the tribes we have yet described; for not only does there seem to be an absence of nervous filaments, but of muscular or fibrous structure; the alimentary canal even, where it exists, is not possessed of distinct walls bounding its cavity, but seems channelled out of the soft parenchyma; and where anything like a circulation of nutritive fluid goes on, it takes place in similar reticulated canals unprovided with proper tunics. In these and

many other respects, the animals composing this division resemble the early condition of the embryo of one of the higher classes; and just as the rapidity of the changes this undergoes in the progress of its development, is proportional to the simplicity of its structure, and to the shortness of the period which has elapsed since its evolution commenced, do we find among the Acrita a peculiar tendency to advance into close approximation with the genera respectively belonging to the higher classes with which they are connected. From this circumstance results the great difficulty which has been felt in assigning definite characters to the division at large; for whatever type of conformation be made the basis of these characters, it is found to undergo the most important modifications, where it presents itself in affinity with those of the other divisions towards which transitions are made. The tendency to repetition of similar parts among the Radiata has been already noticed; and a similar one exists, to a certain extent, in the lower Articulata, where the different segments of the body are almost alike. Among the Acrita, this tendency, so characteristic of the vegetable kingdom, is carried to a still greater extent, and is often exhibited in a very curious manner. Thus, the Sponges, of which the young gemmules swim freely about, are fixed at a later period of life; and in forming their calcareous, siliceous, or earthy skeleton (§ 121), seem to lose the few characteristics of animal life which they before possessed, and in its construction are limited to the repetition of a single spiculum. The Infusorial animalcules, again, are termed *Polygastrica*, from the repetitions of the digestive cavity which occupy the principal part of their bulk. Among the *Sterelmintha* or lower Entozoa, we find a similar repetition of the reproductive system, each joint of the body of the *Tænia* (tapeworm) being the seat of a separate ovary, though all are nourished by continuations of one simple system of nutritious tubes. And in the *Polypes*, the respective mouths and stomachs appear to be to a certain extent independent; being connected together by the gelatinous flesh which clothes the exterior of the axis or lines its tubes (§ 115), but being capable of separation without injury to the general structure, and without the destruction of their own existence.

110. As it is in the animals belonging to this division, that the organs termed *cilia* appear to perform the most important part, in relation both to the nutritive and animal functions, this would seem the proper place to introduce a more particular description of them. Cilia, then, are little hair-like filaments, covering the surface and fringing the edges of various parts, both external and internal, which are in contact with fluid; in which fluid they produce, by their vibrations, currents which may serve various important purposes in the economy of the animal. In the active and free-moving Infusorial Animalcules, the cilia on the exterior of the body are the principal, if not the only organs

of locomotion; in the Polypes, fixed to a particular situation and unable to go in search of their food, the currents which they create in the surrounding element bring it within reach of their tentacula or arms; and in all animals modified for respiration in water, from those simple structures in which no particular part of the surface seems appropriated to this function, to Fishes and the larvæ of the Batrachia, their movements appear to have an important relation with it, in constantly renewing the stratum of water in apposition with the aerating surface. Cilia are even found on the mucous membrane lining the trachea and ramifying air-passages of the higher Vertebrata; and their use appears there to be, to convey the secretions and foreign matters, if such should be present, along the surface. They have also been observed in the upper part of the alimentary canal of Reptiles, throughout its whole extent in Mollusca, and in the stomach and its appendages in the Asterias; as well as in many other situations. The presence of cilia, when they are moving with rapidity, can frequently be only inferred from the eddies which they produce in the neighbouring fluid. Sometimes the return-stroke, which is made more slowly, can be seen when the direct stroke is too rapid to be followed; this is particularly the case in the wheels of the Rotifera (§ 93), which appear to revolve continuously in one direction, from the observer being only able to trace one set of the vibratory movements of the rings of cilia which compose them. In general, however, the cilia may be best seen when their motion slackens; and their shape, size, arrangement, and manner of moving, may then be distinguished with tolerable accuracy. Their figure is that of slender filaments, sometimes a little flattened, and tapering gradually from the base to the point. Their size is extremely variable, the largest being about $\frac{1}{500}$ of an inch long, and the smallest being stated at $\frac{1}{13000}$. They are generally arranged in regular order, sometimes in straight rows, sometimes spirally or in circles; and they are usually set pretty close together. When in motion, each cilium appears to bend from its root to its point, returning again to its original state, like the stalks of corn when depressed by the wind; and when a number are affected in succession with this motion, the appearance of progressive waves following one another is produced, as when a corn-field is agitated by frequent gusts. The motion of the cilia seems to be quite independent of the will of the animal, being seen after death, and proceeding with perfect regularity in parts separated from the body; its duration varies according to the species in which it is observed, and is influenced by many external circumstances; it has been seen fifteen days after death, in the Tortoise, when putrefaction was far advanced; and in the River-mussel it seems to endure with similar pertinacity. It is the opinion of Dr. Grant that the cilia are tubular organs like the feet of the Echinoderma, and that their movements are owing to injection of water from elastic tubes running along the base; but this seems scarcely

consistent with the fact that their vibrations continue when entirely detached from the circulating system. Dr. Sharpey, who has particularly investigated this curious subject,* is disposed to believe with other observers, that the motion is produced by the action of muscular fibres, connected with the base of the cilia, and probably traversing their substance also; their return being perhaps due to their own elasticity when the muscle is relaxed. It is very properly urged that the minuteness of the parts is no argument against this supposition, which seems to derive some weight from the correspondence between the duration of the ciliary motion after death, and the persistence of muscular irritability in like circumstances.

111. It is a matter of little consequence with which class we begin the description of the individual groups included among the Acrita, since they cannot be regarded as possessing much affinity with each other, or any regular gradation of structure. We may first speak of the STERELMINTHA or *Vers Parenchymateux* of Cuvier, a class formerly included among the Articulata, but separated from the Entozoa already described on account of the absence of nervous filaments, the homogeneous character of the textures, and the nature of the boundaries to the digestive cavity. This in the Entozoa (§ 94) is furnished with a distinct tunic, whilst in these simpler tribes it is only channeled out of the substance, and occasionally appears altogether absent. Mr. Owen separates some of the least organised of this tribe, and unites them with the Vibrios and other vermiform animalcules, (which are only found in decomposing fluids, and have been usually placed among the Polygastrica), to form another division which he calls Protelmintha; but they may probably be regarded as belonging to the present type reduced to its lowest condition. Of these, the *eels* of Paste or Vinegar, and others which are parasitic in living vegetables, are characteristic examples; they appear to possess a straight intestinal canal, but no distinct stomachs, and are destitute of external cilia. To this group belongs the very curious parasite which has been lately discovered to be of no unfrequent occurrence in the muscles of the human body, the *Trichina spiralis* (Fig. 91); which is a little worm-like animal about the $\frac{1}{30}$ of an inch in length, lying coiled up in a cyst formed by the inflammation of the cellular tissue that exists between the fibres of the muscle. It is curious that this parasite has only been found in the muscles of animal life; and that even where these are thickly beset with them, the muscles of organic life, namely, the heart and the alimentary tube, are entirely free. It was at first supposed that their existence was connected with a generally-enfeebled state of the system; but they have been since found in healthy men who have died suddenly, as well as in the bodies of those who have suffered from exhausting diseases.

* See Cyclopædia of Anatomy, Art. Cilia.

112. A parasite of even greater simplicity inhabiting the animal body, is the common *Hydatid* or Acephalocyst, which consists of a globular membranous bag, containing a limpid colourless fluid. This so much resembles certain cysts which are occasionally formed in an abnormal state of the nutritive process in the animal system, that much doubt has been felt whether it should be regarded as possessing an independent existence. The best observers agree in stating that the Hydatid is impassive under the application of stimuli of any kind, and that it manifests no contractile power, either partial or general, save such as evidently results from elasticity; in short, that it neither feels, nor moves, nor exhibits any distinctly animal faculty. Its power of reproduction, however, by the formation of gemmæ or buds between its layers, shows it to be entitled to the rank of an independent being; the young Hydatids being thrown off either internally or externally, according to the species. If the views formerly stated (§ 66), however, on the subject of the parasitic fungi, should be ultimately received as an established doctrine, it will not be difficult to apply them to such structures as the present, which approach so near to the morbid growths spontaneously arising in the bodies of higher animals. Other species, such as the *Cysticercus*, have a more complex and definite form; and possess a head armed with spines and suckers for the imbibition of nutriment. This parasite has been observed within the eye of man. Some of these, by their elongated bodies, return again to the vermiform character; and amongst the most remarkable of type, the *Tænia solium* (tape-worm) may be mentioned. This animal has sometimes attained the length of ten feet; its breadth varies from a quarter of a line at its anterior part to three or four lines at its posterior part, where it again gradually diminishes. The head is small, and possesses four mouths, surrounded by a double circle of small hooks. The segments or divisions of the body are very numerous, sometimes amounting to several hundreds; but they are all connected by the nutritive canal proceeding from the mouth, although the reproductive apparatus is repeated in each part. It has been the opinion of some naturalists that each segment of the Tænia might be regarded as a separate animal. This, however, cannot be received; as it is found that the existence of the head is essential to the life of the body; and that, if broken off with some joints attached, it continues to grow and to form new ones, whilst those which have been separated from it die, and are expelled from the body.

113. The next class which may be noticed is that of POLYGASTRICA or Infusorial Animalcules; this was formerly supposed to contain the simplest members of the animal kingdom; but it is now known, from the researches of Ehrenberg and others, to possess, in general at least, an organisation of much complexity. Wherever any decaying organised matter exists in a fluid state, and is exposed to air and warmth, it will speedily be found peopled with minute inhabitants of the most varied

forms, and diversified movements, possessed of considerable activity, and evidently endowed with an energetic system of nutrition. They are, therefore, by no means so nearly allied to vegetables as those inactive and simple creatures, the sponges and their neighbouring species. The cause of the spontaneous appearance of these animalcules where no germs were previously suspected to exist, and where it could not be supposed that they had been conveyed, has been a matter of much speculation. Many have had recourse to the supposition that they formed, in a latent state, a part of the living tissues of the animal and vegetable structures, from the decomposition of which they were evolved; and others have even supposed them to have arisen from accidental combinations of inorganic elements. As yet, however, somewhat of the same obscurity hangs over their origin, as envelopes the propagation of the Fungi; since there is some reason to believe that amongst the Polygastrica, also, the same germ may be developed into different forms, according to the character of the infusion from which it derives its support. But these little animals are not confined to infusions of organised matter; they are found in the stagnant waters around our cities; in the waters of rivers, harbours, lakes, and, even, it is believed, in every fluid drop of the ocean. From their minute size and extensive distribution, therefore, there is reason to suppose that they are the most numerous living beings that exist on the face of the globe. Their tissue is usually soft and gelatinous; but not unfrequently they possess a transparent envelope which appears to be of a horny consistence, but which, in many species, is now found to consist almost entirely of silex. From the late researches of Ehrenberg, it appears that whole rocks of the mineral termed Tripoli or rotten-stone (an impalpable powder used in the arts for polishing), are composed of the siliceous shields of a species of *Navicula*, which seem to differ little from those now existing. Even where the shields cannot be separated in a distinct form, traces of them and of other similar remains are found, as in the consolidated nodules of various flints, opals, &c. It is scarcely possible to imagine the countless multitudes of these beings, which must have existed in former ages, for their very *exuviæ* to have thus accumulated.*

114. The character of the Polygastrica is derived, as their name imports, from the number of their stomachs, which are little dilatations of the alimentary canal, excavated, as it were, from their soft cellular parenchyma. This canal sometimes possesses two distinct orifices (as in the *Enchelis pupa*, Fig. 92), of which the mouth only is usually fringed with cilia; but most frequently the lower extremity of it returns to the point from which it set out, and the same external orifice communicates both

* It is peculiarly interesting to trace such occurrences in progress at the present time. The author has seen water, brought from a lake in the island of St. Vincent, crowded with the shields of races of Naviculæ at present inhabiting it; and the mud which is being deposited in abundance at the bottom of the lake, is almost entirely composed of them.

with the entrance and the termination of the canal (Fig. 77, *a*). The little digestive sacs are very numerous in some species; more than a hundred have been seen in the *Paramæcium* (Fig. 94), filled at the same time; and there may have been many more unseen from their emptiness. The method of viewing them is to introduce into the water some colouring matter, such as carmine or indigo, in a state of minute division; its particles are then received into the intestinal canal, and are very evidently seen through the transparent tissues which surround it. Some among these animalcules, however, seem to possess a more complex structure. Ehrenberg has announced the existence of many distinct organs in them, but it may be questioned whether they are yet altogether demonstrated. In this interesting class we find many different modes of reproduction, which will be more particularly described hereafter (CHAP. XIII.); and the diversities of form and movement which its various species exhibit are of the most extraordinary character. The latter have been thus described:—"Several swim with the velocity of an arrow, so that the eye can scarcely follow them; others appear to drag their body along with difficulty, and to move like the leech; and others seem to exist in perpetual rest; one will revolve on its centre, or the anterior part of its head; others move by undulations, leaps, oscillations, or successive gyrations; in short there is no kind of animal motion or other kind of progression that is not practised by animalcules." Although we may not immediately perceive an object for the existence of such countless multitudes of living beings, there can be little doubt that they serve a most important purpose in the economy of Nature, by supplying food to the larger tenants of the waters; Polypes, Mollusca, Crustacea, and even Fish seem greatly indebted to them for their nutriment; and even the larger animalcules prey upon the smaller ones,—the *Vorticella*, for instance, creating by its wheels a current which draws them into its mouth, just like (it has been amusingly remarked by Spallanzani, *parvis componere magna*,) a certain species of whale, which after having driven herrings into a bay or strait, by a blow of its tail produces a whirlpool of vast extent and great rapidity, which precipitates them down its open mouth.

115. There is probably no group in the Animal Kingdom more heterogeneous in character than that which has been formed into a class under the title of POLYPIFERA or Zoophytes. It is only recently, however, that an increased acquaintance with the structure of its members has revealed the incongruity of their association; and at present therefore we must be content to retain their general designation, until a subdivision shall have been agreed upon. Peculiar interest attaches to this class in the eyes of the Physiologist as well as of the Zoologist; for, as has been remarked,* "they present to him the simplest independent structures

* Johnston's History of British Zoophytes.

compatible with the existence of animal life, enabling him to examine some of its phenomena in isolation, and free from the obscurity which greater complexity of anatomy entails. The means of their propagation and increase are the first of a series of facts on which a theory of generation must rise; the existence of vibratile cilia on the surfaces of the membranes, which has been shown to be so general and influential among animals, was first discovered in their study; and in them are first detected the traces of a circulation carried on independently of a heart and vessels." In describing the principal types of structure, which may be most readily distinguished, it will be convenient to begin with one of the inferior, and, at the same time, best known species. The common *Hydra viridis* (green polype, Fig. 95) is one of the simplest forms of structure, evidently animal, with which we are acquainted. It consists of nothing but a granular and apparently homogeneous membrane, composing a bag, which may be regarded as a stomach; its single aperture or mouth being fringed with *tentacula*, or tendril-like filaments, which are very irritable and contract upon anything which touches them, endeavouring to draw it towards the entrance of the digestive sac. These tentacula are *not* fringed with cilia; and therein consists an important difference between this polype and higher species of whose form it may be regarded as a sketch. Although so simple in its structure, its digestive powers are very energetic, and it appears to exercise considerable force in conveying to its mouth the living animals which it frequently seizes. The contractility of the whole body is very remarkable, and causes the animal to assume entirely different forms at different periods. No trace of fibre is discoverable in its tissues, which seem entirely composed of globules united together by a jelly-like matter. The tentacula of one species *(H. fusca)* have been seen to extend from less than a line to a length of eight inches; and it is not uncommon to see the body ten or twelve times longer at one period than at another, varying in form between that of a long narrow cylinder and that of a tubercle or button. Whilst the want of *cilia* on its tentacula prevents the creation of currents for the purpose of bringing a constant supply of food to the mouth, and thus affords less choice to the animal, the body is so constructed as to be capable of accommodating itself to a prey of very variable size; and, in like manner, the absence of this special means of aerating the fluids, is compensated by the exposure of every part of the tissue, both by its internal and external surface, to the surrounding element. A striking proof of the simplicity of the structure of this Polype is the fact, that it may be turned inside out like a glove; that which was before its external tegument becoming the lining of its stomach, and *vice versâ*. Another very curious result occurs from the same cause,—the extraordinary power which one portion possesses of reproducing the rest. Into whatever number of parts a Hydra may be

divided, each will retain its vitality, and give origin to a new and entire fabric, so that thirty or forty individuals may be formed by the section of one. The regular mode of reproduction in this animal, however, bears no analogy to this. Little bud-like processes are developed from its external surface, which are soon observed to resemble the parent in character, possessing a digestive sac, mouth, and tentacula; for a long time, however, their cavity is connected with that of the parent, but at last the communication is cut off, and the young polype quits its attachment, and goes in quest of its own maintenance.

116. The first sub-division of the Polypifera, termed (by Dr. Johnston) *Hydroida* or *Hydraform*, includes, with the simple genus just described, all those compound structures in which a number of polypes similar to it are associated together. Of this group the common *Sertularia* (Fig. 96) is a characteristic illustration. The *polypidom*, or solid framework formed by a secretion from the soft tegument of the animal, consists of a tubular horny stem, enlarged at the extremities of its branches into sheaths; within these the individuals can retract themselves, although when in search of their food they extend beyond it. Each single polype resembles a hydra in every important respect but this;—the stomach, instead of being closed at the bottom, communicates with the interior of the stem and branches; and the membrane forming the sac may be regarded as a prolongation of that which lines these tubes.* The pulp contained in the hollow stem, rather than the polype itself, appears to be the essential part of the animal; for the latter is not only formed subsequently to it in the first instance, but frequently dies, and is reproduced by it. Although reproduction sometimes takes place by *buds* in these associated polypi, as in the Hydra, a more special apparatus is evolved for this purpose. At certain periods there are formed from particular spots on the stem of the Sertularia and its allies, expan-

* When the stem and branches are examined with a high magnifying power, a current of granular particles is seen running along the axis; which, after continuing one or two minutes in the same direction, changes and sets in the opposite one, in which it continues about as long, and then resumes the first; thus alternately flowing down the stem to the extremities of the branches and back again. The change of direction is sometimes immediate; but at other times the particles are quiet for a while, or exhibit a confused whirling motion for a few seconds, before the change takes place. The current extends into the stomachs of the polypi, in which, as well as in the mouth, a continual agitation of particles is perceptible. When these particles are allowed to escape from a cut branch, they exhibit an apparently spontaneous motion. No contraction of the tube or of the stomach seems concerned in the production of the currents; and their rapidity and constancy appear intimately connected with the activity of the nutritive processes taking place in the parts towards which they are directed. In the *Tubularia*, another polype with naked tentacula, currents of a similar kind have been observed; but in this genus the stem is divided by nodes or partitions, into distinct cavities like the elongated cells of the Chara (§ 62). As on the walls of those cells, a number of slightly spiral dots are seen, in the line of which the current appears to move, passing down one side, crossing at the septum, and ascending the other with an even and uniform motion, just like the globuliferous fluid of the Chara (§ 353).

sions of its structure, somewhat resembling those which encase the polypes, but usually larger (Fig. 96, *b*). They are provided with a lid; and in their cavity are seen a number of gelatinous globules, which are at first connected by cords with the soft tissue at the base of the cell, but afterwards separate from it; and having acquired cilia on their surface, and being liberated by the falling-off of the lid, they swim forth, and after a little time attach themselves to some body which will serve for the support of a new structure. The vesicle, when thus emptied of its contents, soon drops off, like the seed-vessel of a plant after its functions are performed. Each reproductive gemmule consists of two substances, a thin cuticle or envelope, and a contained pulp. The former seems the rudiment of the future horny sheath; and, in the early stages of development, it is distended and moulded by the growth of the pulp within. The latter at first increases longitudinally, and then forms a polype, which bursts its envelope, and commences the active exercise of its functions. The external membrane becomes hardened into the cell, within which the polype can retract itself, and then undergoes no farther change. This division has also been termed (by Dr. Farre) *Nudibrachiata*, from the deficiency of cilia on the arms or tentacula.

117. Another division of Polypifera may be termed *Ciliobrachiata* (Dr. Farre) from the presence of cilia upon its tentacula; or *Ascidioida* (Dr. Johnston), from its affinity with the Tunicata, to which it is closely allied. On a superficial inspection, no very striking difference would be observed between the characters of this group and those of the one just described; but the minute examinations of Milne-Edwards, and Dr. Farre,* have disclosed in the former a degree of complexity of structure, which it would seem scarcely possible to have imagined. In the *Bowerbankia densa* (Fig. 97), for example, we find a horny transparent sheath enclosing the polype, the upper part of which is so flexible as to be capable of being drawn inwards by the action of muscles, thus closing the mouth of the cell. The animal contained in it possesses ten tentacula, fringed with cilia, which surround the mouth of the large open tube, *a*, that forms the entrance to the digestive sac; this leads by a narrow orifice to a globular cavity, *b*, which seems analogous to a gizzard, having thick sides lined internally with tooth-like processes; below this is the true stomach, *c*, a large bag in whose parietes are situated a number of follicles for the secretion of bile, which tinges this part of a rich brown colour. From the upper part of the stomach, not far from the first opening, the intestine passes off by a distinct orifice, *d*, surrounded with vibratile cilia; and this terminates on the outer side of the ring to which the tentacula are affixed. The whole of this complicated digestive apparatus seems to float in the cavity of a membrane which lines the cell, the interspace being filled with fluid. In order to retract it within its

* Philosophical Transactions, 1837.

sheath, and to draw down the upper portion of the latter as its protection, a very curious system of muscles is provided, which probably exhibits this structure in its simplest form, all the fibres being plainly separate. The whole process of digestion may be distinctly watched in this beautiful little animal. The food obtained by the motion of the cilia passes into the mouth, and is propelled downwards to the first stomach or gizzard, by the contraction of the parietes of the tube, as in the highest animals. After being subject to a brief trituration in the first stomach or gizzard, like that which is performed by the masticating apparatus of the Rotifera, it is passed onwards to the principal stomach, where it remains a considerable time for digestion, being sometimes regurgitated, for a second trituration, to the gizzard. The excrementitious matter, which at first appears like little granules, is propelled by the action of the cilia round its second orifice, into the intestine, where it accumulates into small pellets, which are gradually propelled to its termination by the contraction of the tube. No nervous system can be detected in these animals; yet it might almost be inferred from the presence of distinct muscular structure, of which different parts have to be put in action at the same time. The connection of the different cells with each other through the medium of the stem seems to be much less decided than in the Sertularia; but it cannot be doubted that during their young state at least a direct communication with the stem exists. There is considerable variety in the structure of the animals associated in this group; some being more and others less complex than the one now described; but they agree in these two essential points, the possession of a second orifice to the digestive cavity, and the presence of cilia upon the arms.*

118. In this group of Polypes, it appears that the organs of support are more completely a part of the animal structure than in other instances. The horny or calcareous deposit which gives strength to the cell, does not seem an extra-vascular secretion from the surface of the gelatinous pulp, as in the Hydroida, but rather appears to be deposited in the interstices of a reflexion of the membrane which has been spoken of as covering the digestive apparatus. For if one of the calcareous *polypidoms* of this tribe be submitted to the action of acid, its form is not destroyed, but a flexible membranous substance remains, like that which is left after *bone* has undergone a similar action. The reproductive apparatus does not seem essentially different from that already described in the Sertularia. The

* A very common form of this group is the *Flustra*, so often mistaken for a sea-weed. The branches of an ordinary specimen may present about 10 square inches of surface; each square inch contains about 1800 cells; each polype has usually 22 tentacula, and each tentaculum about 100 cilia. So that on such a specimen there would be more than 18,000 polypes, 396,000 tentacula, and 39,600,000 cilia. Other species certainly contain more than ten times these numbers; Dr. Grant has computed about 400,000,000 cilia to exist on a single *Flustra foliacea*.

development of the ciliated reproductive gemmule into the perfect animal has been carefully watched and described by Dr. Grant. After swimming about freely for some time, it fixes itself, and begins to spread as a flat expanded jelly. It soon secretes white particles of calcareous matter, which form the outline of an entire cell; and its walls become gradually more defined and stronger. The rudiment of a polype then appears at the bottom, but this has at first no cavity; subsequently the membrane which envelopes it opens at the top, the tentacula are formed, and the whole of its complicated organism is evolved by degrees. In the mean time, the gelatinous margin of the gemmule has extended much beyond the boundary of the first-formed cell, and produces others in like manner. When we add to this history of the first devolopment of these animals, the fact that a portion of the gelatinous flesh removed from the surface will also form cells and produce polypes, it becomes evident that the polype is not the essential part of the structure, as was formerly supposed.

119. The next group, that of *Asteroida* (Johnston), or Alcyonian Polypes, presents evident affinities with the Radiata. In the structure of the individual polypes, we return in part to the type which characterised the first class, the digestive cavity having no second orifice. But the simple stomach of the Hydraform tribes is rendered complex by the union of the reproductive apparatus with it. The name Asteroida is given to this division, from the star-like appearance of its eight short thick tentacula, which, when expanded round the mouth, present the aspect of an Asterias. One of the simple forms of the polypes of this group is that of the *Alcyonium eros*, shown in Fig. 98, where *a* is the mouth, *b* the tube extending into the common mass, and *c* a separate tube in which gemmules are developed; the latter opens into the cavity of the stomach, and the gemmules, when mature, pass out by the mouth. In other species, the tubes are multiplied, or the structure becomes more complex in other ways. Between the lining of the stomach and the outer envelope of the *Alcyonidium elegans* (Fig. 99), there is a considerable space, which is subdivided by radiating partitions into eight chambers. In these chambers, which communicate with the tubular tentacula above, and unite in the general cavity below, the gemmules are produced; they appear at first like little protrusions from the surface of the membrane, which gradually acquire a separate form, remaining attached only by a cord; and when this has separated, they find their way into the stomach, and pass out by the mouth. The character of the general mass by which the polypes are supported and connected, varies much in different species. In the *Alcyonium*, it has throughout somewhat of a cartilaginous texture, and not unfrequently contains calcareous spicula: it is intersected by tough fibrous bands, and permeated by ramifying canals, which connect the polypes; so that it is not unlike a mass of firm sponge, furnished with polypes at the entrance of its pores; and before these are developed, it might almost be

mistaken for a fabric of that class. In the common *Red Coral*, on the other hand, the flesh itself is softer; but it deposits a mass of calcareous matter which forms its solid central axis; and its integument also is firm, and contains crystalline particles. No cells are here found on the axis itself, the polypes being imbedded only in the soft flesh, and protected by the firm integument. Other species form a horny skeleton in the same manner; and in the curious *Isis hippuris* (Fig. 100) the axis has a regular jointed structure, arising from the deposition of earthy matter at intervals only, leaving the intermediate portions and the extremities soft and flexible. Such a conformation evidently points towards the more regular skeleton of the Crinoidea. No very massive structures are ever produced by this group of polypes; the axis having usually an arborescent form, and being more or less flexible. The *Pennatula*, or sea-pen, is said to have active locomotive powers, the polypidom being carried through the water by the ciliary movements of the polypes; but this is doubtful.

120. The last division of the Polypifera is that which contains the *lithophyte* species, which build up the massive foundation of the coral islands. Of these, the common *Actinia* (sea-anemone) may be regarded as the type; and the group may be denominated Actiniform, or (by Dr. Johnston) *Helianthoida*, from the resemblance that the mouths of the polypes bear to the sun-flower. The Actiniæ, like the Hydræ, are solitary animals; but some of the species in which many such are associated, exhibit an almost indefinite extension of the same individual; if a continuous mass of gelatinous flesh, uniting innumerable polypes, is to be regarded as such. The body of the Actinia is broad and flat, compared with that of other polypes; the mouth is surrounded by concentric rows of short, ciliated, tubular tentacula; the stomach has but one orifice connecting it with the exterior, but its cavity is partially subdivided by folds or plaits of its lining membrane; and between its walls and the general envelope are chambers similar to those just described in the Asteroida (except in not communicating with the cavity of the stomach), and apparently having the same function (Fig. 101). The skin of the Actinia is leathery, and forms an epidermis which may be traced over its exterior, and even into the stomach. The massive polypidoms constructed by associated polypes, may be regarded as analogous to this epidermis; they are formed upon the mould, as it were, of the animal; and the cells usually exhibit a set of radiating lamellæ, which correspond with the division of the chambers surrounding the stomach. All the cavities are capable of great distension; and in the Actinia, fluid seems to enter and to be ejected, not only through the mouth, but through the tentacula also. Water appears to be thus introduced for the purpose of aerating the tissues; and it is remarkable that the whole of the internal surface is covered with cilia, as well as the tentacula. The vast importance of these beings in the economy of Nature is now well ascertained, not only

by observation of the changes which they are producing on the present surface of the globe, but by examination of the structure of solid calcareous rocks, which generally prove to have been formed from the *debris*, more or less disturbed, of coralline structures.

121. There can be little question that if the class PORIFERA is to be ranked in the animal creation, the lowest place in the scale is justly assigned to it; since the beings included in it exhibit so few indications of any but organic life, that it has been, and perhaps still may be doubted, whether they should not rather be assigned to the Vegetable Kingdom. The tribes of *Sponges* and their allies are those which constitute the group. The fleshy portion of the body is extremely soft, so as in fact to drain away when the mass is removed from the water, like the white of an egg, or the vitreous humour of the eye; hence its existence was for a long time overlooked, although it is now known to clothe the firmer structure, to which the term of *sponge* is given, and which serves as its skeleton. This framework is constructed of fibres arranged with considerable regularity, so as to form the sides of the canals which permeate the mass, and to surround their orifices. The fibres are in general partly of an animal character, being composed of a substance like horn, and of tubular structure; but with these are usually mixed spicula of earthy matter, presenting different shapes according to their material. When they are calcareous they have a tri-radiate form; but they are often siliceous and are then usually needle-shaped. It is not a little interesting, that in this group of animals we

should meet with the same ingredients employed to give density to the structure, as in the vegetable kingdom. In no other class does silex enter largely into the organs of support; but it is well known to be very abundant in plants, which also contain carbonate of lime, sometimes to a considerable extent. The form which these structures present is extremely variable, while their general character differs but little. Sometimes they are branched and ramified, hanging from the under surface of rocks; occasionally they grow in the form of cups, which have been often seen three or four feet in height, and with a diameter of more than a foot, and which also grow in a depending position; and not unfrequently they spread as encrusting masses over rocks, shells, stones, and other submarine substances. In the living state, the Sponges appear to be constantly imbibing fluid by their minute pores; this traverses the ramifying canals in the interior of the body, in contact with the soft flesh which lines them, and is expelled in a constant stream by the large orifices. It is impossible to assign a cause for this movement; no cilia have been discovered in any part of the adult animal; and the tissues are altogether possessed of so little contractility, that it is difficult to suppose the fluid to be propelled through the tubes by any mechanical

influence on their part. If motion of this kind were all that is exhibited by these creatures, it would not be sufficient to establish their claim to an animal character, since a similar circulation, of which this might be regarded as a magnified view, takes place in the vessels conveying the nutritious fluid of the higher plants (§ 286—290); but previously to their assuming the adult form, the little reproductive gemmules swim about freely, and to appearance voluntarily, by means of the cilia with which they are furnished; and hence they have been regarded as unequivocally belonging to the animal kingdom. Even this, however, is a doubtful character; for it will hereafter be seen, that the sporules or reproductive granules of the Algæ (§ 520) are as active before fixing themselves, as the gemmules of the Sponges; and no doubt is entertained of their vegetable nature. Altogether, then, it may be surmised that this group occupies the very borders of the kingdom in which it is placed, exhibiting the characters of animality in the most feeble degree; and it is so closely connected with the lowest class of Plants, that there are many tribes whose proper location cannot yet be determined. In some sponges, however, the orifices of the large alimentary canals are so much prolonged as to approach the form of the simplest of the Polypifera.

122. Having thus passed, in brief review, the principal groups which naturally present themselves to our notice in the Animal Kingdom, it remains to show the manner in which their grand divisions are connected together, and then to enquire how far these may be regarded as in any respect analogous to those which have been established among plants. Starting from the Acrita, in which we find the simplest and at the same time most varied forms of animal structure, the transition is easy to the Mollusca, by those higher species among the Polypes which have been mentioned as almost constituting a distinct class, and as being closely allied with the Tunicata. Rising from this, the lowest class of Mollusca, to the Cephalopod tribes, we manifestly approach the Vertebrata. From the Vertebrata, the transition to the Articulata has been shown to be easy, by the occurrence of vermiform suctorial fishes so simple in their structure, that, were it not for the characters presented by their nervous system, they might almost be associated (as the older naturalists did associate them) with the Leech and its allies. In the higher Articulata, especially the Insects, we find the Annulose type of structure carried to such perfection, that in the characters peculiarly animal, its members far surpass the inferior species among Vertebrata. Their peculiar tendency, however, appears to be towards the high development of the *instinctive* powers, by which all their actions are guided with the greatest uniformity; whilst among the Vertebrated classes a gradual subordination of these to the reasoning faculties may be observed. These tendencies are found to be associated with certain characters presented by the nervous system; the central organs of which are among the Vertebrata consolidated into one

principal ganglion, and in the Articulata distributed among many. As has been well observed by Mr. Macleay, "Perfection among the Annulosa seems always tending to make the animal a complicated machine, guided solely by the instinct implanted in it by its Creator; whilst in the Vertebrata, perfection seems to tend to make the animal a free agent, and to render it more independent of external circumstances." Between the Articulata and Radiata, a very manifest connection is effected by such animals among the latter as the Holothuria and Siponculus, which, with the general structure of the Echinoderma, present such a remarkable tendency to the Annulose form; as well as by the class Cirrhopoda among the former, the shell of which is formed so much upon the plan of that of the Echinus: and from the Radiata, we may return to the Acrita by numerous links of transition, such as the group of Acalephæ, the Actiniæ which approach so near to some of the Star-fish, and others. The circle of affinities may therefore be expressed in the following manner:

Cephalopoda.	VERTEBRATA.		ARTICULATA.	*Holothuridæ.*
	MOLLUSCA.	ACRITA.	RADIATA.	

123. This is only expressing, in a different form, what was long ago perceived by Lamarck, that the Articulata and Mollusca cannot be regarded as succeeding each other in any scale ascending in a single line from the lowest to the highest of the animal creation; but that from the group included by Cuvier in the sub-kingdom Radiata (with which the beings here called Acrita were associated), a passage might be formed to the Vertebrata through two distinct tracks or series. If these divisions be admitted as naturally expressing the principal types of structure which prevail in the animal kingdom, a very curious series of analogies may be pointed out, which indicate their correspondence with those already stated as the primary groups of the vegetable world. In making such comparisons it should be carefully borne in mind, that we must not expect to find among plants any characters analogous to those peculiar to the animal kingdom; and that we must therefore be guided rather by the general plan of structure, and the arrangement of the vegetative organs, than by any of those details which, in the higher classes of animals especially, are so much modified by their connection with the functions of relation. For it must be recollected that whilst *perfection* in the vegetable kingdom has reference to the nutritive system alone, amongst animals it is the manifestation in the highest degree of the powers of sensation and locomotion, and of the psychical faculties which are connected with them. Keeping these principles in view, therefore, we may proceed to a more particular enquiry into the analogies just referred to.

124. That the closest affinity between the Animal and Vegetable Kingdoms exists in their respective groups of ACRITA and PROTOPHYTA, every naturalist is well aware; and those who have examined the matter less scientifically find so near a resemblance in their forms, that the visitor of the sea-coast almost always associates his Algæ and Polypifera in the collections he makes there. Nor when enquiry is made into the details, is it always easy to effect the separation; since the simplest forms of animals aud plants approach each other so closely in structure, that no diagnostic mark can distinguish them, and the supposed presence or absence of sensibility and voluntary power are all the criteria which we possess (§ 220). The correspondence in the condition of their nutritive functions is peculiar throughout these two groups; for whilst the sea-weeds imbibe the alimentary fluid at every part of the surface, the same universal power of absorption appears possessed among the lower Acrita, both by the outer tegument and the inversion of it which forms the lining of the stomach; and whilst, among the Lichens, we usually find one surface dry and hard, and the other especially adapted for absorption, so do the higher Acrita present us with many illustrations of the restriction of the absorbent power to the sides of the digestive cavity, the external surface being more or less excluded from it by the hardness of its envelope. Another very interesting correspondence between the Acrita and the Protophyta may be noticed. It has been well remarked that, in the construction of the lowest and simplest of the animal kingdom, nature so far from forgetting order, (which in their most dissimilar forms might almost appear to have been left out of view), has, at the commencement of her work, given us a sketch of the different forms which she intended afterwards to adopt for the whole animal kingdom. Thus, among some of the soft sluggish Entozoa, we have the outline of the Mollusca: in the fleshy living mass which surrounds the earthy axis, formed in concentric layers, of the floating Polypi, she has sketched a vertebrated animal; whilst in the crustaceous covering of the living tissues, and in the structure, more or less articulated, of the sheathed Polypes, we trace the form of the annulose classes.* It would not be difficult to trace, in like manner, among the ever-varying forms of the Protophyta, the outlines of the four remaining divisions of the vegetable kingdom. The representation of Mosses among the Lichens, and that of Fungi among the Lichens and Algæ, have been already noticed; and among the sea-weeds we may distinctly trace indications of the Endogenous structure in the hollow stem of the *Laminaria buccinalis*, whilst the Exogenous mode of growth is still more frequently manifested. It would be too long to pursue this subject into its ramifications; and the following quotation from the writings of M. Agardh, one of the most eminent cryptogamists of the present day, must therefore suffice for the present. "Inter inferiores

* Owen in Cycl. of Anat. I. p. 49.

formas, superiores sæpe efflorescunt, sed rudes et veluti experimenta; sic anticipationes formæ perfectioris in plantis inferioribus non raro obveniant; ut etiam in plantis superioribus regressus ad formam imperfectiorem."

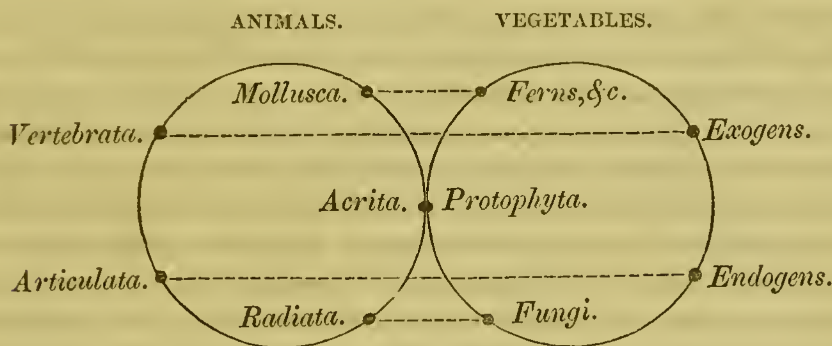
125. Passing on to the FUNGI and RADIATA, we may observe a resemblance manifested, in the first place, generally, by the tendency exhibited in the higher divisions of the former group to that regular arrangement of parts around a common centre which is so characteristic of the latter; and, again, by the very curious analogies in the position of the reproductive organs between various Medusæ and Echinoderma, on the one hand, and species occupying a similar place among the Fungi on the other. To show that these comparisons are not forced or puerile, the language of Agardh may again be quoted. "Fungi superiores Animalia Radiata, ob figuram radiantem, ob superficiem nudam, ob texturam laxam, ob colorem subsimilem, non male revocant."

126. The sub-kingdom MOLLUSCA bears several analogies with the group of FERNS and MOSSES, of which the following may be shortly mentioned. It is among the Ferns and their allies that we observe the spiral mode of development more evident than in any other branch of the vegetable kingdom; being indicated not only in the arrangement of the leaves round the stem, but in the development of the leaves themselves. This spiral tendency is also manifested in the Gasteropoda, the typical Mollusca, more strongly than in any other animals, and the mode in which the stem of ferns is formed by additions, consisting of the adherent petioles, to its extremity alone, bears a very close analogy to the growth of the shell of the Mollusca, by the formation of a new lamina at its edge. In these plants, too, as among the greater part of the Mollusca, there is no distinct separation of the sexes.

127. The correspondence of ARTICULATA with ENDOGENS, as well as that of Vertebrata with Exogens, was long ago pointed out by Desfontaines, who first discovered this primary natural division of the Phanerogamia founded on the structure of their stems. Thus, both of the groups just mentioned have their hardest portions, or organs of support, placed externally; in both, the additions to their tissue are formed from within; in both also there is usually a distinct division into segments, each of which in plants, as in the lower annulose animals, contains the organs essential to its vitality; and in Endogens, as in Insects, are the *tracheæ* (respiratory tubes, § 26) distributed through the whole system. The hard external parietes of these classes undergo little or no change in diameter when once fully formed; but Endogenous plants have not the power of occasionally throwing them off, which is possessed by most of the Articulated animals.

128. In like manner, EXOGENS may be considered analogous to VERTEBRATA in the internal situation of their hard parts, the formation of new tissue from without, the less distinct division into segments, and the

confinement of the internal respiratory apparatus to a particular situation in the fabric. As in the hardened tegument of many Vertebrata we observe the remains of the external skeleton of the lower animals, so in the formation of the bark of Exogens by additional layers from within, we trace the remnant of the Endogenous structure; and the process of decortication can scarcely fail to remind us of the exuviation of the skin among serpents, an order in which the Annulose form is so strongly marked, and which thus retains one of its leading characteristics. The following table will place in an obvious aspect the respective positions of these principal groups of the Animal and Vegetable kingdoms:—



It is the opinion of some Zoologists that the primary distribution of the Animal Kingdom is into *three* groups, Vertebrata, Annulosa, and Mollusca; the last division, comprehending the Mollusca proper, Radiata, and Acrita, would then obviously be analogous to that of the Cryptogamia amongst vegetables, which includes Ferns and their allies, Fungi, and Protophyta.

129. It will be seen that in the foregoing arrangement what is called the *circular system* has, to a certain extent, been adopted. Naturalists have long been aware that both in large and in small groups it is impossible to arrange the individual parts in such a manner as to begin with the lowest and end with the highest; but that from whatever point we start, we may, by pursuing the various gradations of structure presented to us, return to that point again. A very interesting illustration of this principle has been given when the class of Reptiles was described. Botanists have recognised the same tendency from the time that the natural arrangement was first pursued; and the power of thus tracing a peculiar type of conformation through all its varieties, without being checked in any part by a broad hiatus, may be regarded as characteristic of a complete natural group. The affinities of its members should not, however, be complete within itself alone; for the various modifications which the principal type undergoes, should exhibit so many transitions to the neighbouring groups. The typical member of any group will be that one which exhibits its peculiarities of form, structure and economy in

the greatest perfection, without any one being predominant over the others; and hence the *types* of different groups will be much more widely separated from one another, than those *aberrant* members, as they are termed, which possess these characters in a less remarkable or less united degree, some being modified or softened down, as it were, to meet those of the neighbouring division. Thus, nothing can be more unlike than an Insect and a Star-fish, or than a Snail and a Herring; yet we find them connected by an almost perfect chain; and where there are deficiencies, it does not seem improbable that future discoveries may supply them. For the more we know of the internal structure of recent and extinct animals, the more are we enabled to demonstrate the general truth of the aphorism of Linnæus "Natura non fiat per saltum."

130. It may be doubted whether the circular arrangement is competent to express *all* the affinities which a truly natural group will present. Thus, the Acrita are represented by it as passing towards the Articulata only through the medium of the Radiata; whilst it is evident that between the higher Entozoa, which from the complexity of their structure are justly associated with Insects, and those simpler vermiform species, which from the simplicity of their organisation can scarcely be removed from the Acrita, there is an equally close affinity. Abstractedly speaking, therefore, it is probable that a natural group is to be represented by a *sphere* rather than a *circle;* its typical form being regarded as the centre, and its aberrant members connecting it by affinity with its neighbours in *all* directions. If, then, this modification of the system would seem to be required to preserve its harmony with nature, (and it is useless to pursue any system as a means of attaining to the knowledge of Nature's laws which does not constantly preserve this harmony), we shall be still more disinclined to adopt the opinion of those who maintain —not only that every natural group forms a circle, touching the neighbouring ones on each side, and all these entering into the formation of a larger circle;—but that the number of divisions in each circle throughout the whole animal and vegetable kingdoms is exactly *five.* It is scarcely possible to believe that Nature been so restricted; and although some of the leading classes, as those of Birds and Insects among animals, and of Exogens and Endogens among plants, appear naturally subdivided upon this plan, its applicability to other groups is very doubtful. A very beautiful theory has been created by Mr. Swainson and others upon the circular mode of arrangement; but as the basis is not yet firm, the superstructure is still less so. Each division of a circular group is regarded as presenting the characters of the type of that group, modified according to a certain fixed plan. Thus, in the Mammalia, whatever may be the peculiar character of the order, as that of Bats or Marsupialia, one division will always be carnivorous, another will have an aquatic tendency, another will have long tails, and so on. Upon this hypothesis, each

division of one group will present a certain correspondence with the similar division of every other group, whether of the same rank with itself or not, since they are all formed upon the same plan; hence these corresponding divisions may be regarded as *representing* each other throughout the whole kingdom. It cannot be denied that we constantly meet with exemplifications of this doctrine, both among plants and animals; but its universality has been by no means established.

VIII.—*Symmetry of Organised Structures.*

131. No one can observe the external forms of the animals which commonly present themselves to his notice, without remarking an uniformity of the parts composing the two sides of the body, which is termed *symmetry*. But symmetry may exist, not only where there is this evident correspondence of two halves, (in which case it is said to be *bi-lateral*); but also in the regular arrangement of many similar parts around a common centre, as in the Asterias, Echinus, and others of the Radiata; or in a spiral disposition of similar organs around a cylinder, which is the regular type of symmetry in the Vegetable kingdom. Moreover, although there may be symmetry of external form, the internal organs may not be alike on the two sides; this is the case in nearly all Animals. We shall enquire, then, what general principles can be specified, as to the symmetrical arrangement of the organs of plants and animals.

132. In many of the simpler tribes of Plants, although there is a mode of growth peculiar to each species, it is difficult to recognise, in the general indefiniteness of form, any well marked symmetrical characters. Thus, in the simpler ALGÆ, LICHENS, and FUNGI, the growth of each individual is so modified by circumstances, that it would be impossible to assign any determinate boundaries to its outline; and there is no doubt that hasty attempts to characterise different races by their external forms, have led to much erroneous multiplication of species. Proceeding to higher tribes of the CRYPTOGAMIA, however, we soon find an evident tendency to symmetrical disposition of parts. Thus, in the more perfect FUNGI (such as the Mushroom tribe), there is a circular stem surrounded by a system of organs regularly radiating from it as a centre.* In the MOSSES we find abundant evidence of a spiral arrangement of the leaves around the axis; and in the FERNS, this disposition of the organs is a remarkable and striking character of the group. The fronds composing the crown that surmounts the stem in those arborescent species which add so much to the beauty of the tropical landscape, are evidently arranged in a spiral form around it.

133. Although amongst the PHANEROGAMIA there are many individual instances of the same tendency, yet it cannot be universally recog-

* It is probable, however, from what will shortly be mentioned, that this arrangement, though apparently circular, is really spiral.

nised, except by the philosophic botanist. It may be regarded, however, as the general law of the arrangement of the branches, leaves, and parts of the flower, that they are disposed spirally around the axis of growth; although the proof of this arrangement, in numerous individual cases, would be difficult, owing to the interference of perturbing causes. The theory of the *spiral* development of the leaves, &c. around the stem, is found to account for all the varieties occurring in their arrangement; and where *opposite* leaves (as in the honey-suckle), or *verticils* or whorls (as in the strawberry) have been thus produced, they will again be rendered *alternate* or spiral, by any cause which restores the stem to its full development. It has now been completely established that the laws of the arrangement of the leaves are equally applicable to the disposition of the parts of the flower, each of which may be regarded as a different form of a common rudimentary type (§ 54). In a regular flower, the bracts constitute the first or external verticil,—the calyx, the second,—and so on. That the parts of each division of the flower should appear to arise from the same circle on the axis, only results from the non-development of the latter; and although, therefore, their symmetry might appear to be *circular*, yet it is in reality *spiral*. This is shown by the fact that the verticils of the flower are sometimes separated, like those of the leaves, by the increase in length of the stem on which they are situated; as not uncommonly happens in the double tulip.

134. It appears, then, that where there is determinate symmetry of form in the vegetable kingdom, it is manifestly of a spiral character. Now a spiral* is evidently formed by the union of a circular and a longitudinal motion. The latter is usually produced, in the growing plant, by the development of the axis; but where this is from any cause checked, a *circular* arrangement is the consequence. This would seem the probable explanation of the form of the Fungi; and we shall find a remarkable analagous instance in the Animal Kingdom (§ 136). This tendency to spiral development is exhibited, not only in the arrangement of the leaves, &c. upon the axis, but sometimes in the form of the stem itself, (as in the group of climbing plants), or in its internal structure. Each twining species has a determinate direction, which is generally from right to left, as in the Convolvulus, Passion-flower, &c.; but sometimes from left to right, as in the Hop: and this cannot be artificially changed without breaking the plant, or stopping its growth.

136. In the lowest group of animals, that of the PORIFERA, we may perceive a similar want of definite form, to that which was noticed in the corresponding tribes of plants; and the first indications of symmetrical arrangement of parts, are found in the tentacula which fringe the oral apertures of the POLYPES. As to the form of the Polypidoms (§ 116)

† A *helix* is the more correct mathematical term for the curve; resembling that of a cork-screw, which is here intended.

themselves, a bi-lateral symmetry may be occasionally observed in the *free* species, the *Pennatula* (§ 119) for example; whilst in many of those which are *attached*, a branched appearance is exhibited, which may perhaps be regulated by laws of the same kind as those which govern the vegetable structure they so much resemble. Among the *Alcyonian* Polypes, circular symmetry is apparent, and through them we pass to the Radiata; whilst in the *Sterelmintha* we have a sketch of the bi-lateral symmetry of the Articulata. In the RADIATA we find the most remarkà-specimen of *circular* symmetry that the Animal Kingdom exhibits. No one can fail to remark the extreme and beautiful regularity of the dispo-position of the numerous plates of the Echinus or Asterias, or of the several portions of the Comatula or Pentacrinus, around a common centre. Late investigations, have, nevertheless, rendered it almost certain that the development of these animals proceeds, like that of plants, upon a *spiral* type; for Agassiz has shown that whilst the number of pieces is increasing, the new ones are added on this plan.* It is easy to see how the want of longitudinal development shall occasion this apparent deviation, as in the instances among plants which have been already explained. That the Radiata should preserve the mode of development which we have seen to characterise the Vegetable Kingdom, is not surprising, when we reflect upon the very small portion which their *animal* functions bear to those of organic life. None of them possess any high degree of sensibility; and whilst many of them are fixed like plants during a part or the whole of their existence, none possess any very active powers of locomotion. As a general rule, then, it may be stated that *circular* or *spiral* symmetry exists where a number of organs of similar character, (which thus repeat each other, like the leaves of plants, or the rays of a star-fish,) are associated together into one fabric.

137. In the sub-kingdom ARTICULATA, on the other hand, the tendency to *bi-lateral* symmetry is carried to its greatest extent. Throughout the whole, we observe a perfect correspondence between the two sides, in external shape; and even some of the nutritive organs, which in higher classes of animals maintain their asymmetrical form (such as those of circulation and respiration), are here developed equally on the two sides. It is among the Insect tribes that the locomotive powers are carried to their highest development: the instruments adapted for this purpose are, of necessity, perfectly balanced on the two sides; and the arrangement of other systems is made to coincide as much as possible with the same plan.

138. In the sub-kingdom MOLLUSCA, on the contrary, we find a tendency of precisely an opposite kind. Every thing in them is sacrificed to the high development of the nutritive apparatus; the locomotive

* He also considers that there is some degree of bi-lateral symmetry in these classes; but it is only such as a *flower* presents, the regular disposition of whose parts enables it to be equally divided by a median line.

organs are in general only adapted for slow and feeble progression; and in many instances the animals of this class are fixed to some immoveable support during nearly the whole of their lives. We find, accordingly, that there is a total want of bi-lateral symmetry throughout the group, except in those highest members of it, the CEPHALOPODA, the structure of which borders on that of the Vertebrata (§ 96). Of these it may be observed, that a bi-lateral symmetry is evident in the external form of the naked species, such as the Cuttle-fish, in which the locomotive powers are the greatest. It is in the class of GASTEROPODA and those Cephalopoda which border upon it, that we remark the spiral arrangement of the different parts of the apparatus of organic life, carried to the greatest extent which it attains in the Animal kingdom. Here also we find the phenomenon of *reversion* by no means unfrequent. The usual direction of the spires of shells is from left to right; but there are some genera and species in which the contrary direction is universally taken *(Planorbis)*, and others in which it is occasionally exhibited *(Buccinum undatum)*. In the Conchifera, we find a general want of lateral symmetry connected with feeble locomotive powers, except in a few instances, where the two halves of the shell and their contained parts have more than usual resemblance.

139. In the Vertebrata, the locomotive system of the Articulated classes may be regarded as united with the nutritive apparatus of the Mollusca. The high development of the animal powers requires the perfect adaptation of the external organs to the purpose of voluntary movements; and we consequently find that these are always arranged so as to present an exact uniformity of the two sides. But this uniformity is only external; for the various parts composing the nutritive apparatus are developed more or less upon an asymmetrical plan. The situation of the heart, liver, pancreas, &c., the relative size of the lungs and of the oviducts in birds, are instances of this tendency, which has not been overcome by the opposite system so completely as in insects. Still, however, it is worthy of remark that during the progress of the development of the higher Vertebrata, there is evidence of more perfect bi-lateral symmetry of the organs of nutritive life than is subsequently maintained. Thus, the situation of the heart and the arrangement of the large vessels are, at an early period, nearly similar as to the two sides of the body; and at a later epoch, the liver extends nearly as far on the left side as on the right. Instances of the *reversion* of all these organs are not unfrequent, the heart and stomach being found on the right side, the liver on the left,—and so on. It cannot be doubted that the cause of this transposition of the viscera is the same as that of reversion among the Mollusca.

BOOK I.

GENERAL PHYSIOLOGY.

CHAPTER I.

ON THE NATURE AND CAUSES OF VITAL ACTIONS.

140. There is no department of philosophy around which so much unnecessary mystery has been cast, as the investigation of the character and laws of the Phenomena of Life. And this veil of mystery will long continue to baffle the curiosity of those who have not received, either directly or indirectly, the mental training which the pursuit of Physical Science affords. To designate any of the actions of a living body,—whether its reception of food from without, its conversion of that food into the materials of its own structure, the movements of its parts upon one another or of the whole fabric, its production of other beings like itself,—as *vital*, or as effected by the *vital principle*, has long been regarded as placing a sufficient check upon further enquiry. The history of Physical science shows, however, that it was once labouring under the same restraint, and that until the true objects of investigation were understood, scarcely any advance was made. Thus, in past ages all the phenomena of the movements of the heavenly bodies were attributed to the operation of some vague "principle of motion," the laws of which it was considered impracticable to attain. In like manner, the simple optical fact—that when the sun's light passes through a hole, the bright image, if formed at a considerable distance from it, is always round, instead of imitating the figure of the aperture,—was attributed by Aristotle to the "circular nature" of the sun's light; whilst the simple consideration, that the rays of light travel in straight lines, would, if properly applied, have explained this phenomenon, not only as regards the sun, but in the case of any other round luminous body placed at a sufficient distance. To refer all the operations of Life which cannot be explained by physical laws, to a

"Vital Principle," is in reality to proceed just as unphilosophically as the ancients did in the cases just quoted: since a strict examination into their character will show that, although not *identical with* physical phenomena, they are *analogous to* them; being the results of the operation of the vital properties which are peculiar to organised matter, just as the physical changes of inorganic matter result from the operation of its mere physical properties. The characters and laws of these Vital properties are as open to investigation as those which give rise to the phenomena of Gravity, Electricity, or Magnetism; although more difficult of attainment, owing to the intricacy of the combinations in which the results are presented to our observation (§ 4).

141. Few terms have been employed in a greater variety of significations, or more frequently without any definite meaning at all, than the word *Life.* The older philosophers regarded it as a distinct entity or substance residing in certain forms of matter, and the cause both of their organisation, and of the actions exhibited by them.* We have seen that the tendency to rest satisfied with vague hypotheses of this kind, operated in the retardation of Physical Science; and had it not been for the comparative prominence and simplicity of its phenomena, it is not improbable that even at the present day we should hear employed in *it* such terms as the "Vital Principle," "Organic Agent," or any other equally unphilosophical refuge of those physiologists who neglect the substance to grasp at the shadow. To the term *principle* no very definite meaning can be attached. It has been remarked that "this word, characteristic of a less advanced state of science, has been generally employed (as the final letters of the alphabet are used by algebraists) to denote an unknown element, which, when thus expressed, is more conveniently analysed." Thus, it has been customary to speak of the principle of gravity, the principle of electricity, or of the principle of magnetism, as the unknown causes of certain phenomena that are as yet imperfectly comprehended. In so far, however, as the laws of these phenomena are understood, they terminate in referring all the results to simple properties of matter, from which they may be deduced by demonstrative reasoning, just as geometrical theorems from the postulates on which they are founded. Thus, the law of gravitation, —which is only an expression of the property inherent in masses of matter, of attracting others, and of being attracted by them,—joined with those of motion, which are equally simple, explains all the movements of

* Every sect had its own notion of the origin and nature of this entity; some regarding it as a kind of fire; others as a kind of air, or ether, or spirit; and others, again, as merely a kind of water. The fable of Prometheus embodies this doctrine in a mythological form, the artist being described as vivifying his clay statues by Fire stolen from the chariot of the Sun. And whatever was the idea entertained as to the character of this agent, all regarded it as universally pervading the World, and as actuating all its operations in the capacity of a Life or Soul, whilst a special division of it—a *divinæ particula auræ*—regulated all the concerns of each individual organism.

the heavenly bodies, in whose phenomena we may witness their operation uncontrolled by any other agencies, and of which the astronomer is thus enabled to predict the perturbations as well as the regular motions. And it is probable that all the phenomena of electricity and magnetism will, ere long, be generalised to the same extent,—that is to say, will be reduced to an expression of equal simplicity; and that a still higher generalisation will then include all those now alluded to. It has been in the Science of Life that the term *principle* has been most used, and most abused. It must be admitted that the conditions of vital phenomena are not yet determined with sufficient precision, to enable us to refer all observed facts, through the medium of general laws, to simple vital properties; and there might be no peculiar objection to the use of the term "Vital principle," as a convenient expression for the sum of the unknown powers which are developed by the action of these properties. But care must be taken not to rest satisfied in its use.

142. The terms *Vital Principle*, and *Life*, are commonly employed almost synonymously, to imply the controlling agent by which the phenomena of living beings are directed, if not immediately produced. Thus, it is frequently said that the action of Physical and Chemical laws is modified or entirely checked by the living principle. Now if we come to analyse this expression, we shall find it to mean one of two things;—either that the living principle is a distinct intelligent agent, capable of harmonising all the actions of Physics and Chemistry, and of rendering them subservient to its government, employing them in fact as subordinate agents to execute its mandates;—or that the actions in question result from the mixed operation of those properties which organised structures possess in common with inorganic matter, and of those which are peculiar to the former. In the first sense it means *every thing*, for to the Vital principle all meaner agents must then acknowledge their subordination; in the latter case, it means *nothing* more than would be better expressed in other language, free from cavil or misapprehension.

143. The doctrine of a Vital Principle is not only quite unnecessary to explain facts, but is totally unsupported by the analogies of Nature, and by what we know of the Divine Government in general. No reflecting mind has any doubt that this earth and its inhabitants form a system, of which every part is perfectly adapted to the rest, (so that we might almost call it an *organised* one, if the idea of a particular structure were not involved in the term,) and of which all the actions and changes, however in appearance contrary, have one common tendency, the ultimate happiness of the creatures of Infinite Benevolence. It cannot be regarded as an improbability that the other spheres and systems,—whose countless multitudes, revealed by the aid of science, impress our minds with the nearest conception of infinity of which our finite comprehension is capable,—are peopled with beings, if not similar in structure with our-

selves, at least equally worthy of the Creator's care. In the government of our own planet, itself but a point in the vast universe, we are able to recognise, to a small extent, the laws by which its physical changes are guided; and we discern faint glimmerings of those by which the moral condition of sentient beings is controlled. So far as we can understand the mutual adaptation of these laws, we everywhere see them working to the same end; and we entertain the highest anticipations of that beauty and harmony which will be revealed to us, when our imperfect glimmerings of knowledge shall be extended and corrected by the light of Eternal Truth. Should we not consider it degrading to the dignity of Infinite Wisdom to suppose that at the creation of each world, He had found it necessary to delegate to a subordinate the control over its working,—instead of at once impressing upon its elements those simple properties, from whose mutual actions, foreseen and provided for in the laws according to which they operate, all the varieties of change which it was His intention to produce, should necessarily result?

144. The harmony of means and ends is shown in the structure of the universe, not less than in the adaptation of the parts of a single organised being to one another. And if the actions of the former can be reduced to simple and general laws, which are but expressions of the Divine Will, there is nothing absurd or unphilosophical, or derogatory to the dignity of living beings, in the belief that those of the latter may be ultimately placed on the same footing. For if we come to enquire into the function of any single organ, or, in other words, into the nature of the changes produced by it, we find that it may be referred to the property of the structure, manifested or called into action by a *stimulus* of some kind, to which it is expressly fitted to respond. This is evidently the case even in the inorganic world. The process of evaporation, for example, will not take place when fluid is exposed to an atmosphere already saturated with moisture; since one of the conditions of the action is a dry air capable of dissolving watery vapour, or, still better, a vacuum into which it may freely rise. In the same manner, the electrical properties of matter are not manifested by one mass alone; to exhibit electric or magnetic attractions and repulsions, two substances are necessary. In machines constructed to take advantage of the physical properties of matter, and to bring them into useful operation, a *stimulus* to their action is required, in some means which shall develope these *properties*, and thus create *powers*. Thus, the power of gravitation is called into exercise, when the clock-weight is wound up; that which results from elasticity, when the main-spring of a watch is coiled within the barrel; that of the expansibility of gases generated by combustion, when a cannon-ball is propelled by the ignition of gunpowder. In the Steam-engine we have a still closer parallel with the mechanism of organised structures, since this apparatus consists of a *number of parts*, having

functions which are totally distinct in themselves, and yet all tending to a common purpose. In the construction of the steam-engine, (at least in the usual forms of it), advantage is taken of *two* of the properties of water, and means are provided to bring these into operation *against* one another, yet still with a common end. Thus, heat is applied to the boiler to generate steam, the expansion of which is employed as one motive force; whilst cold is applied to the condenser, to produce a vacuum by the condensation of that steam, against which vacuum the expansive force may act with greater advantage than against the elastic air. Heat and cold, then, properly applied, may be regarded as the two *stimuli* which are essential to excite the machine to action; and without these, however perfect might be its structure, however beautiful and harmonious the adaptation of its parts, it would for ever remain dormant.

145. It must not be imagined for a moment, however, that any intention is here implied of identifying the structure and actions of an organised being, with those of a steam-engine or any other such piece of human mechanism. The latter is framed to take advantage of the properties with which the Creator has endowed all forms of matter, inanimate as well as animate. But the actions of a living being incontestably show that beside these properties, there are others which are exclusively confined to organised tissues; and if we compare these with the general structure of the fabric, we shall find that its mechanism is adapted to bring them into the most advantageous relation with one another. Thus, the circulating system is a piece of apparatus which acts chiefly upon physical principles, the fluid impelled by the heart moving through its ramifying canals, just as water ejected from a forcing pump might traverse elastic tubes of similar construction; and its object is to bring the alimentary materials which have been absorbed, into contact with the tissues whose nutrition they are to supply. The powers which move the blood may altogether result from vital operations; yet the motion itself is strictly conformable to physical laws. Different Schools of Physiologists have erred in opposite extremes, with regard to the agency of these laws, or, in other words, of the physical properties of matter, in the production of vital phenomena; some attributing all the actions of living beings to the immediate operation of the vital properties of their structure; others maintaining that they are of a purely physical nature. The truth appears, with regard to this, in common with so many disputed questions, to lie in the mean between the opposing extremes; and it will be the object of much of the present work to show where the boundary line may be most naturally drawn.

146. If the application of the term *Life* to some imaginary agent which is the immediate cause of vital phenomena, be found useless or injurious, it may reasonably be enquired what is to be understood by it. If we regard as a *living* being, an organised structure which we observe

growing and moving and resisting decay, it is evidently no improper use of the term to designate by it the *sum of all the actions* performed by such a being, from its first production to its final dissolution. Observation of these actions leads us to arrange them, as has been already stated (§ 6), into certain groups termed Functions; and analysis of the functional changes exhibited by living beings, terminates in referring them all to certain properties possessed by their component structures; which properties stand in the same relation to organised tissues, as do those of gravitation, electricity, &c., to matter in general. Their existence must, for the present at least, be regarded as ultimate facts in physiology. They are called into action by *stimuli* of various kinds, adapted to excite each of them to its own peculiar operations. Now, although the adaptation of the various functions to one another, and the manifest tendency of all the vital processes to a common end, would appear, at first sight, to favour the idea of a presiding power by which the whole is regulated, a little consideration will show that these *really* imply no more than an original adaptation of the structure and properties of the organs by which they are performed. Every tissue has its own laws of development, (some of which have been glanced at in the Introduction, III—V); but all these laws are subservient to one general principle,—that every organised structure is produced by a previously-existing organism, no living being ever taking its origin from spontaneous combinations of inorganic matter (§ 516). Our enquiry leads us back, therefore, to the first creation of each species; and here we may again revert to the character of Physical laws, as illustrating the more obscure nature of those of Vitality.

147. The term *Law* of Nature, as already employed, expresses the *conditions of action* of the properties of matter. The Divine Creator of the universe "has, by creating his materials, endued with certain fixed qualities and powers, impressed them in their origin with the *spirit* not the *letter* of his law, and made all their subsequent combinations and relations inevitable consequences of this first impression."* In other words, the unchangeableness of His nature is manifested by his continued action in the material creation, according to the same plan by which He at first adjusted the relations of its parts. Our belief in the uniformity of Nature, which leads us to seek for a common cause when a number of similar phenomena are presented to our observation, is based, not only upon experience, but upon the conviction which every believer in the existence of the Deity feels of His immutability. If it were otherwise, we should be led by *analogy* only to infer the existence of law and order where none is evident; but the mind which is once satisfied of the existence of a Creator, possesses a moral *certainty* that to him must belong a Consummate Wisdom, which shall contrive the attainment of

* Herschell's Preliminary Discourse, p. 37.

every end by the best adapted means,—an Omnipotence, which shall have all these means at full command,—and an Omniscience, which shall foresee in every action not only its immediate but its remotest consequences. To imagine, therefore, that the plan of the Universe, once established with a definite end, could require alteration during the continuance of its existence, is at once to deny the perfection of the Divine attributes; whilst, on the other hand, to suppose, as some have done, that the properties first impressed upon matter would *of themselves* continue its actions, is to deny all that revelation teaches us regarding our continued dependence on the Creator. Let it be borne in mind, then, that when a *law* of Physics or of Vitality is mentioned, nothing more is really implied than a simple expression of the *mode* in which the Creator is *constantly* operating on inorganic matter, or on organised structures.

148. That there was a period antecedent to the creation, not only of the animated beings which at present people this globe, or whose remains we find imbedded in its depths, but also of the whole material universe itself,—we are assured alike by reason and revelation. That subsequently to its creation it has remained unchanged by any other powers than those developed within itself by the agency of the laws to which it was at first made subject, all Physical philosophy tends to prove.* The motions of the heavenly bodies have not varied in the minutest degree from the standard to which they conformed at the earliest periods of observation; and did we know all the causes operating in the production of terrestrial phenomena, we should undoubtedly be able to predict their operations with the same certainty as we can foretell the occurrences which the planetary revolutions will exhibit to us. The fundamental uniformity in the changes which the animated world presents, is no less striking, when the superficial or apparent varieties are stripped off (§ 2,3); and this becomes most evident when we trace back each individual race to its origin. If we conceive that at that period the Parent of all impressed upon the elements of which each created being was composed, the spirit of the laws which should in future govern its growth and reproduction, (just as He impressed upon the bodies composing the planetary system, that mode of action whose subsequent continuance has given us the notion of the laws of gravitation and of motion), we require nothing but the continued operation of those laws, or, in other words, the continuance of the same mode of action, to account for the perpetuation of the

* Miraculous interpositions for the purpose of effecting upon the mind of man such an influence as would not be produced by the contemplation of the uniformity of nature, are of course excluded from the present enquiry. If these are exceptions to general laws, they are so only in human estimation; since they are as much a part of the Divine Will, and were as much foreseen by Divine Omniscience, as any of those occurrences which are usually regarded as constituting the *order of Nature.*

race. To suppose that the adaptation of these laws to each other and to those of the external world, could be otherwise than perfect, would be to cast a stigma upon Infinite Wisdom. What they are, it is the object of the physiologist to ascertain by observation and generalisation of the phenomena resulting from them; and he certainly will not derive any assistance by setting out with the notion of a secondary presiding existence, however refined he may imagine its character to be.

149. The properties which are peculiar to organised tissues, and to which inanimate matter affords no analogy, are said to be *vital;* and the possession of such properties by a living being, or by a single organ, is termed its *vitality.* Thus, muscular fibres have the power of contracting when stimulated by mechanical or chemical agents; and those composing certain muscles are also thrown into contraction by the application of stimuli to the nerves which supply them, or by the propagation of a stimulus originating in the will of the being, along the efferent nervous trunks from the brain. In the first case we have the vital property, the *contractility*, of the muscle alone concerned; in the second, we perceive a respondence on the part of the muscle to nervous influence, and a capability on the part of the nervous system of receiving and transmitting impressions, both mechanical and mental. In neither instance can we discover any such mechanism in the structures by which these properties are exhibited, as would enable us to attribute the effects to any peculiar operation of the physical properties of matter; and we are therefore led to regard them as of a character entirely new, more especially since they are evidently dependent upon the integrity of the structure by which they are manifested, and cease to exist, if its due relations with the organism in general are seriously disturbed. It is a question which has been vehemently discussed, but which is after all more one of words than of realities, whether vital properties are the *result* of organisation, or that peculiar combination and arrangement in which the elementary particles of living beings are disposed,—or whether they are to be regarded as *superadded* to it. This can only be fairly discussed after the meaning of the term *property* has been fixed.

150. A little consideration will show that, whilst man derives his knowledge of the external world from the impressions made by matter under some of its forms upon his organs of sense, he can form no conception of matter as any thing distinct from the properties which thus affect him. The notion of hardness, for example, is only derived from the resistance offered to his touch; that of colour, from the impression made by luminous rays upon his retina. Some of the properties of matter are thus *immediately* cognisable by man, because they at once produce changes in his organs of sense, which excite a corresponding affection of his sensorium. But there are others from the knowledge of which man is debarred, until the material object is brought into circumstances adapted to develope

them. Thus, if but one mass of matter existed in the universe, it *might* be endowed with all the properties which we are accustomed to regard as essential to matter; and, yet, from the property of gravitation never being brought into action with another body, the mind might remain ignorant of it. In the same manner, a body might be in a certain magnetical condition; yet, from the want of others with which to exhibit attractions or repulsions, the property might remain undiscovered. But it is not difficult to imagine that a being might be formed capable of discovering these properties by his senses alone, just as man recognises colours, tastes, &c.; and might, at the same time, be unable, without some intermediate agency, to take cognisance of those, of which the human senses at once inform the mind of man; or, again, might be susceptible of impressions quite different from any of which we can form an idea. It will, then, scarcely be denied that the term "property of matter" simply denotes its capability of producing an effect upon the percipient mind, by its action on the sensory organs, either immediately, or through the medium of some other; and that it cannot imply any agency distinct or separate from matter. It is further evident, that no judgment can be formed of the presence or absence of any property, unless the body which is the subject of investigation be placed in all the conditions requisite to test its existence. Thus, supposing a new metal to be discovered, we should have no ground for decision as to its magnetic properties, until it had been brought into every conceivable relation with magnetised substances.

151. It cannot, then, be logically correct to speak of vital properties as *superadded* to organised matter, although an apparent analogy has been drawn from physical science in support of the assumption. It is commonly said that a living body, in assimilating and organising the nutrient matter by which the changes necessary to its existence are maintained, superadds, or communicates to it by a separate act, those vital properties of which it was itself previously possessed; and there is no more difficulty, it has been argued, in conceiving how vital properties may be communicated to organised matter, than in understanding how magnetic properties may be superinduced upon iron. But the analogy is based upon a false conception of the latter process, which is really conformable in character to those by which gravitation or any other properties of matter are brought into action. For the so-called communication of magnetic properties to iron, is nothing more than the production of a change in the conditions of the metal, by which the electric properties, which previously existed in that as in every form of matter, are manifested, and caused to give rise to magnetic powers. If an analogy exist between the two processes (which can scarcely be denied), it leads us to the belief, that just as the magnetic powers are developed in iron, when the metallic mass is placed in a condition to manifest them, so the very act of organisation developes vital powers in the tissues which it con-

structs. For no one can assert that there does not exist in every uncombined particle of matter which is capable of being assimilated, the ability to exhibit vital actions, when placed in the requisite conditions; in other words, when made a part of a living system by the process of organisation. It is only the complexity of the conditions required to manifest it, which prevents our recognising this capability as a common property of matter, or, at least, of those forms of it which we know by experience to enter into the composition of organised structures.

152. Experience and observation lead to conclusions not dissimilar. Organisation and vital properties are simultaneously communicated to the germ by the structures of its parent; those vital properties confer upon it the means of itself assimilating, and thereby organising and endowing with vitality, the materials supplied by the inorganic world. As long as each tissue retains its normal constitution, renovated by the actions of absorption and deposition by which that constitution is preserved, and surrounded by those concurrent conditions which a living system alone can afford, so long, have we every reason to believe, it will retain its vital properties, and no longer. And just as we have no evidence of the existence of vital properties in any other form of matter than that denominated organised, so have we no reason to believe that organised matter can retain its regular constitution, and be subjected to its appropriate stimuli, without exhibiting vital actions. The advance of pathological science renders it every day more probable that derangement in function always results, either from some structural alteration (although this may be of a kind imperceptible to our senses), or from some change in the character of the stimuli by which the properties of the organ are called into action. There is no difficulty, therefore, in accounting on this view for the death of the whole system from the cessation of one function; since any perturbation in the train of vital actions will not merely disturb the regularity of all, but, if sufficiently serious, will check those nutrient processes, on the uninterrupted continuance of which the vital properties of the several parts depend; the degree of that dependence being proportional to their respective tendencies to spontaneous decomposition if not thus renovated.* Still, the vital properties of individual parts may be retained for a considerable period after general or

* Thus, in Syncope, the circulation is *immediately* suspended by causes which primarily check the heart's action; and if, as sometimes happens, the same cause extend itself to the capillaries (as in the stroke of lightning, or other sudden and violent impression on the nervous centres), death is almost immediate. Whilst in Asphyxia, where the aeration of the blood in the lungs is prevented, and a stagnation takes place in the pulmonary capillaries, the circulation is *gradually* enfeebled, the functions of the nervous system are suspended for want of their proper stimulus, and the movements of the heart diminished, the right side being paralysed from over-distention, the left from want of excitement. If, in this state, the obstruction to the circulation be removed, the whole system may speedily recover; but if it continue, every organ speedily loses its characteristic properties, and death takes place.

somatic death (§ 153) has taken place; and vital *actions* may be performed in them, so long as the conditions which those organs require in the living body are supplied. Thus, the organic functions of a decapitated animal may go on for a considerable time, if the respiratory movements be artificially continued; its circulation, generation of heat, and the various changes of nutrition and secretion may be maintained; and all this after the being has been reduced, as it were, to the condition of a plant, by the abolition of those powers which characterise its existence as an animal. That the respiratory movements, which are ordinarily executed by the nervous system, must in such a case be artificially maintained, is evident; as in this way only can the conditions be afforded which are necessary to the continued aeration of the blood.

153. The term *death*, therefore, has more than one signification. It may be used to denote the separation of that bond of union which so peculiarly unites all the functions of the living system; rendering each so dependent on the other, that the cessation of one involves that of all the rest. Or, when applied to individual parts, it may signify the loss of their peculiar vital properties, either from some change in their organisation, or from the cessation of those actions by which their structure is maintained in its due perfection; and their consequent subjection to the laws of matter in general. The first change may be termed *systemic*, or more properly *somatic* death; the second *molecular* death. The latter is not always the *immediate* consequence of the former, but must sooner or later result from it. And, on the other hand, the latter may affect individual parts, and not occasion destruction of the organism in general. The dependence of the integrity of the system upon the actions of any particular part, is modified in two ways: first, by the importance of its function to the vital economy; second, by the restriction of the function to that organ, or its diffusion through the whole structure. Thus, in man the power of seeing or of hearing is not essential to the continuance of life, since the social relations of the individual prevent his suffering from the deficiency of food, which would be the necessary consequence of the abolition of these functions in many of the lower animals, to which such faculties are essential. And, on the other hand, any obstruction to the action of the lungs is speedily fatal in man, because these organs almost exclusively minister to the aeration of the blood, which is constantly required for the maintenance of its purity; whilst in frogs, life may be continued for a considerable period after the lungs have been removed from the body, because respiration is not restricted to them, but is performed by the skin with almost the same activity. This explanation, then, at once affords the key to the fact, that the lower animals are almost impassive under injuries which would be fatal to those higher in the scale. Their organs are frequently but repetitions of one another; or, at any rate, their functions are not restricted to particular portions in

anything like the same degree as in the latter; so that destruction or removal of one part does not imply the cessation of its function, which may be continued, more or less perfectly, by some other. But if it were possible to abolish the function completely without injuring other parts, death would then ensue as certainly as in the higher animals. Thus, if the lungs be removed from a frog, and its skin be covered with varnish, it will be speedily asphyxiated.

154. That molecular death, or the loss of vital properties, is in general speedily followed by the separation and dissolution of the elements of the structure, common observation teaches. Reason has, however, been already given (§ 18) for the belief that the affinities which hold together the elementary particles of organised structures, are not different from those concerned in the inorganic world; and it has been shown that the tendency to decomposition after death bears a very close relation with the activity of the changes which take place in the part during life. If this be true, it is obvious that the decomposition which follows death, and which is its most unequivocal sign, does not result from the loss of any particular bond which united the elements during life, but merely from the change in the conditions of the substance which proceeds from the cessation of the vital actions going on within it. That there are cases in which a very feeble degree of vital action is sufficient to preserve the properties of a structure, will be presently shown; but when these altogether cease, the organism must be secluded from all the external influences which could injuriously affect it, in order that its vitality may be preserved. And this seclusion, if carefully practised, is as effectual upon dead matter as upon living; for it is now well ascertained that no perceptible change will ensue in substances which would ordinarily run into rapid decay, if they are rigidly kept from the contact of air and at a moderate temperature.

155. But the mere cessation, whether apparent or real, of vital *actions* does not constitute death. Their suspension may result from the want of the *stimuli* which are necessary to excite the dormant properties to exercise. Thus, seeds may preserve their vitality for periods of indefinite length, if not exposed to those agents which will stimulate them to germination; and the persistence of their properties may be demonstrated by their exhibiting the usual changes, when the requisite stimuli are at last supplied. It is scarcely correct in such a case to say that the seed is *alive*, since *life* (in the sense in which the most philosophical modern physiologists employ it) is synonymous with *vital action*; but it is possessed of vital properties or of *vitality*, so long as no destructive changes take place in its organisation. One of the most interesting cases of this kind on record is related by Dr. Lindley.* "I have now before me," he says, "three plants of Raspberries, which have been raised in the

* Introduction to Botany, p. 298.

gardens of the Horticultural Society, from seeds taken from the stomach of a man whose skeleton was found 30 feet below the surface of the earth, at the bottom of a barrow which was opened near Dorchester. He had been buried with some coins of the Emperor Hadrian, and it is probable, therefore, that the seeds were sixteen or seventeen hundred years old." Instances are of very frequent occurrence, in which ground that has been turned up is found to produce plants dissimilar to any in their neighbourhood. There is no doubt that in some of these, the seed is conveyed by the wind, and becomes developed in particular spots which afford congenial soil; and this fact has a very interesting bearing upon the question of the production of animalcules in infusions of decaying organic matter. Thus, it is commonly observed that clover is ready to spring up on soils which have been rendered alkaline by the strewing of wood-ashes, or the burning of weeds; and it is stated by Professor Graham that after any hill-pasture in Scotland has been laid dry and limed, and the surface broken, white clover always makes its appearance. But there are many authentic facts which can only be explained upon the supposition that the seeds of the newly-appearing plants have lain for a long period imbedded in the soil, at such a distance from the surface as to prevent the access of air and moisture; and that, retaining their vitality under these circumstances, they have been excited to germination when at last exposed to the requisite conditions.*

* Several cases of this kind are related by Dr. Prichard (Researches on the Physical History of Mankind, vol. I, p. 39, &c.) on the authority of Professor Graham; amongst them is the following :—"To the westward of Stirling there is a large peat-bog, a great part of which has been flooded away by raising water from the river Teith, and discharging it into the Forth, the under-soil of clay being then cultivated. The clergyman of the parish standing by while the workmen were forming a ditch in this clay, which had been covered with 14 feet of peat-earth, saw some seeds in the clay which was thrown out of the ditch: he took some of them up and sowed them; they germinated and produced a crop of Chrysanthemum septum. What a period of years must have elapsed while the seeds were getting their covering of clay, and while this clay became buried under 14 feet of peat-earth." For the following not less interesting case, hitherto unpublished, the author is indebted to his valued friend Dr. Tuckerman, of Boston, N. E. "About 25 or 30 years ago, Judge Thacher, then one of the Judges of the Supreme Court of Massachusetts, told me that he knew the fact, that in a town on the Penobscot river, in the state of Maine, and about 40 miles from the sea, some well-diggers, when sinking a well, struck, at the depth of about 20 feet, a stratum of sand, which strongly excited curiosity and interest, from the circumstance that no similar sand was to be found anywhere in the neighbourhood, and that none like it was nearer than the sea-beach. As it was drawn up from the well, it was placed in a pile by itself; an unwillingness having been felt to mix it with the stones and gravel which were also drawn up. But when the work was about to be finished, and the pile of stones and gravel to be removed, it was found necessary to remove also the sand-heap. This, therefore, was scattered about the spot on which it had been formed, and was for some time scarcely remembered. In a year or two, however, it was perceived that a large number of small trees had sprung up from the ground over which the heap of sand had been strewn. These trees became, in their turn, objects of strong interest, and care was taken that no injury should come to them. At length it was ascertained that they were Beach-Plumb trees; and they actually bore the Beach-Plumb, which had never before been seen except immediately upon the sea shore. These trees had,

156. That many animals are capable of being reduced to a state of similar inactivity, and of being again excited to action, cannot be doubted. Thus, insects have revived on exposure to the sun, after having been immersed in spirits for many months; and fishes after being frozen. Wheel-animalcules will recover even after being completely dried up (§ 93). In all those which possess a complicated nervous system, a portion of it is occasionally in a passive state, that of profound sleep; and the part of it which remains active is only that concerned in the maintenance of the organic functions. Sleep, therefore, is to the active state of the animal system, that which the torpor of the seed is to its organic life; in both cases there is a suspension of activity, but a retention of the vital properties which ensures the capability of its renewal. The state of *hybernation*, to which many animals are subject, partly resembles the torpor of the seed; still there is never in them a total suspension of vital action, but only a great diminution. It is curious to observe among the Mammalia the gradations which are exhibited in the different modes of passing the winter, from the Lagomys, which lays up during the autumn a supply of food, and spends the season in a state of sleep, from which it is frequently roused by the calls of hunger,—to the Marmot, which is completely inactive during the whole period, taking no food, and exhibiting scarcely any evidence of life, unless aroused. In the latter case, the organic functions are performed with little activity, but they are not entirely checked; slight respiratory movements are perceptible at distant intervals, and the circulation is feebly carried on;* nor do the nutritive and excretory functions seen altogether inactive, since the fat which had previously accumulated is in general partially absorbed. The disuse of the locomotive powers obviously renders unnecessary those changes which are essential to the maintenance of their active condition; and the organic functions, therefore, need do no more than preserve the integrity of their structures.

157. After many laborious enquiries into the conformation and habits of hybernating animals, physiologists have in general come to the conclusion that they exhibit no peculiarities which can account for their difference. It seems, too, that although the tendency to this state is modified by temperature, it is not altogether dependent upon that condition; and that it is not solely occasioned by *cold*, is evident from the fact that some animals

therefore, sprung up from seeds which were in the stratum of sea-sand that had been pierced by the well-diggers. By what convulsion of the elements they had been thrown there, or how long they had quietly slept beneath the surface of the earth, must be determined by those who know very much more than I do."

* In the Hamster, the pulse usually beats at the rate of 150 per minute; but it is reduced to 15 in the torpid condition. Marmots, in a state of health and activity, perform about 500 respirations in an hour; but in the torpid state, these occur only about 14 times during the same period, and are executed with intervals of four or five minutes of absolute rest, and without any considerable enlargement of the chest.

become torpid during the hot season in tropical climates. It appears reasonable, then, to regard this state as, like sleep, one which the organs are *periodically* disposed to assume; and just as sleep may be induced or delayed by the influence of external circumstances, hybernation may be also. Vegetables, also, at least a large proportion of them in cold climates, pass into a state of hybernation, their leaves dropping off, and their vital functions becoming almost entirely inactive. They may, however, be again roused by increased temperature (§ 289); but even where a plant with deciduous leaves is kept during the autumn in a hot-house, its leaves drop off at the usual time, although it may speedily put forth a new crop. That this unnatural condition, however, exhausts the energy of the plant, is well known; and it becomes particularly evident, when a species adapted to the temperate zone is transplanted to a tropical climate. In evergreens, which maintain a feeble activity during the winter, the processes of growth are never so energetic as in other plants; there is in most of them no definite period for the shedding of the leaves, which fall off and are replaced gradually.

158. The preservation of vitality by seeds depends upon their not being submitted to any of the agents which would call them into activity, or which would tend to disintegrate their structure. The very stimuli which would operate in exciting the vital properties, as long as the organism retains them, have the effect of facilitating its decay when death has taken place. Thus, a moderately elevated temperature, moisture, and the access of oxygen, are the conditions requisite for germination; and all these equally favour the decomposition of the organised substance of the seed, if its vital properties have been destroyed. We shall hereafter see reason to believe that the changes which *immediately* result from their action are of a strictly chemical nature in the former case as well as in the latter (§ 350); but these changes become subservient to the operations of vitality while this remains unimpaired. The vitality of a seed will be destroyed by any thing which produces a change in its structure or composition, however inappreciable the effect may seem. Thus, immersion in water at the temperature of 160° will kill the greater proportion of seeds; and nothing but a very minute examination would discover any structural alteration in their tissues; collateral experiments, however, prove that this is just the temperature at which the vesicles of *fecula* (starch) are ruptured (§ 349); so that this physical change, produced by a physical agent, which the vitality of the structure is unable to resist, is evidently the cause of the destruction of its peculiar properties. In the same manner, it can scarcely be doubted that when the vitality of an egg is destroyed by an electric shock, or by moderate exposure to heat, the agent produces, in obedience to chemical laws, some alteration in the material structure which is inconsistent with the continued existence of its dormant life.

159. Of the actions performed by living beings, many *evidently* possess

a simply physical character. The properties of the organs by which they are performed, are common to them with many kinds of inorganic matter; and they are exhibited by dead as well as by living organised substances, as long as no obvious change takes place in their composition. Hence we may separate them, with some degree of precision, from those which are vital and cease with life; when those tissues, at least, are made the subjects of investigation, which are not prone to rapid decomposition. Thus, no one will deny that the *elasticity* of organised tissues depends, like that of steel or glass, upon a particular state or arrangement of its particles; and that if this necessary condition (of which the physical philosopher is as profoundly ignorant as the physiologist) be but partly fulfilled or entirely wanting, that property is only slightly displayed or is totally absent. In the living body the elasticity and contractility of the tissues require for their maintenance a definite relation between the solid fibres and the fluids in their interstices, a condition which is maintained by the circulating and absorbent apparatus. If the fluids be scanty, the tissue is dry and stiff; if they be superabundant, it becomes over-distended, and loses its elasticity, like an over-strained bow.

160. The same observations will apply to another property of certain organised tissues,—that of permitting the passage of fluids through them, under particular conditions (§ 243, 4). This property is manifestly dependent, like elasticity, upon the ultimate arrangement of their particles, since inorganic matter may become the instrument of producing the same phenomena, when the requisite conditions for the performance of *Endosmose* are supplied. It is commonly stated that the *subversion* of physical laws by those of Vitality is proved by this fact amongst others,—that tissues and membranes which completely retain fluids during life, or only permit certain portions of them to transude, give free passage to them after death. But if the enquiry be pushed a little further, it would probably appear that the peculiar property of the membrane during life depends upon an arrangement of its molecules which can only be maintained by the activity of the nutrient functions; and that it is the cessation of these, and the consequent alteration in the structure of the membrane, which determines the change in its properties. These are instances, among many which might be cited, of the participation of physical agents in the phenomena of Life; but it is still to be remembered that the physical properties themselves are dependent, both for their existence, and for their excitement to action, upon those vital processes which no mechanical contrivances or chemical operations can produce or imitate,—a beautiful series of actions and reactions which cannot but excite our admiration of the skill of the Supreme Contriver.

161. The changes which have been just adverted to, appear chiefly concerned in maintaining the relation between the organised system and the external world. Thus, it will be hereafter shown that the Absorption of

nutritious fluid is probably due to the physical power of Endosmose (CHAP. V.); and the interchange of gaseous ingredients between the air and the blood in the act of Respiration, to the transmitting power which all membranes possess (CHAP. IX). But the continuance of these, and of many more which might be named, is peculiarly dependent on the continuance of other vital actions, and can only be effected in dead matter by processes which imitate these. For example, the Absorption of fluid by the roots of a plant ceases as soon as the demand for fluid in the stem is suspended by the death of the leaves or the interruption of their functions; but it may be re-excited by the appropriate means, so long as the delicate tissue of the Spongioles (§ 248) retains its integrity. On the other hand, a continued absorption may be produced by a physical contrivance which imitates the effects of vital action; as in the wick of a lamp, which draws up oil to supply the combustion above, but will cease to do so when the demand no longer exists. In the same manner, the constant aeration of the blood is dependent upon the continuance of the passage of the fluid over the respiratory membrane; but it may take place to a limited extent after death, as where the livid colour of the skin in Asphyxia gives place to a rosy hue, by the arterialisation of the blood in its capillaries.

162. There is another set of changes in which vital actions would seem yet more intimately concerned, but which still appear to be *immediately* dependent upon the same laws as those which regulate inorganic matter. These consist in the production, from the alimentary materials, of *organic compounds*, either such as gum, sugar, albumen, gelatine, &c. which are destined to be still further organised, or such as urea, cholesterine, &c. which are to be thrown off from the system. This process must not be confounded with that of *organisation*, since it only *prepares* the materials upon which that is concerned. It will be hereafter shown, that the nutritious elements contained in the food do not serve for the support of the structure, until they have been united into new combinations (sometimes, probably, having been first decomposed for that purpose); and there appears good reason to believe that these preparatory changes are of a strictly chemical nature, since many of them are imitable in the laboratory of the philosopher. There may be recognised in them, more or less distinctly, the action of physical laws operating under those peculiar conditions which the living organism alone can perfectly supply; and in so far as the skill of the chemist can imitate those conditions, he may hope to produce similar combinations, as to a small extent has already been effected. But no one can ever hope to effect the *organisation* of such products, or their conversion into living structures; since this is unqestionably an action of a strictly *vital* character, and, as far as we at present know, is dependent on the previous existence of some other organising body.

163. Reasons have been already given for the belief, that the affinities which hold together the elements of organised tissues, are the same as those which prevail in the inorganic world. It is still a fair subject of enquiry, however, what difference exists in the character of the processes of organic chemistry, which produces such evident modification in the results. The chief ground for the assumption of a distinct set of *vital affinities* (as they have been termed) appears to be, that whilst man has the power of effecting or controlling those changes which are produced by physical laws (so far as the materials concerned in them are within his reach), and can therefore imitate to a great extent the immense variety of combinations which the mineral kingdom affords, he is at present unable to effect or control the action of similar materials, so as to produce any of the class of organic compounds or proximate principles. Every fresh discovery, however, tends to show that the powers *immediately* concerned, are, like the elements on which they act, the same in all cases; the difference in the effects produced being due, not to any alteration in the physical properties of the constituents, but solely to the manner in which they are brought to bear upon one another. We cannot yet succeed in producing artificially any organic compound, even of the simplest kind, by directly combining its elements, because we cannot bring them together in their requisite states and proportions; but there is no reasonable ground for doubt that if the elements could be so brought together by the hand of man, the result would be the same as the natural compound. For the agency of vitality, as Dr. Prout justly remarks, "does not change the *properties* of the elements, but simply combines them in *modes* which we cannot imitate." Those who are acquainted with the influence of temperature, electricity, light, the *form* of the body operated on, and the state in which it is presented for combination,—on chemical actions in general, must be well aware how greatly the effects are modified by slight differences in any one of these conditions; and it scarcely seems too much to assume that, ignorant as we are of their influence in the living organism, the acknowledged differences in the results may be dependent upon their operation,—other conditions also, whose nature is yet unsuspected, having perhaps a share in their effects.

164. The view which is here advocated—that the conversion of alimentary materials into organisable products, adapted for the immediate nutrition of the living tissues, is caused by the operation of physical laws acting under those peculiar conditions which a living organism alone can supply—derives considerable support from the fact, of which several examples will be hereafter given (CHAP. VIII.), that some of these products are convertible into others by agents of a purely chemical nature. It is also borne out by the fact that the operations of Vital Chemistry are attended, like the changes in the composition of inorganic substances, with a disturbance of electrical equilibrium (§ 500); and that some of

the less complex of these operations are effectually stimulated by the artificial application of electricity (§ 186). As the late researches of Dr. Faraday have fully proved the identity of electrical attraction with chemical affinity, the instances just mentioned go far to justify the inference that there is no distinct set of forces to which the term Vital Affinities can be fairly given. It is a rule in all philosophical speculations not to frame any hypotheses which are unnecessary to account for phenomena. Those who have attended to the progress of Chemical Science during the last few years, can scarcely hesitate in the belief that we as yet know little of the laws which govern the changes in the constitution of bodies, compared with what future discoveries will reveal to us. Many phenomena of inorganic chemistry, which can now be readily explained, would have been regarded, within a very recent period, as quite incomprehensible. Would it have been thought possible, for example, by a chemist thirty years ago, that the same substance should act the part of an *acid* in one case, and of a *base* in another?—that *water* should be possessed of such properties?—or, still more, that *muriatic acid* should act as the *base* or electro-positive ingredient in combination with the chloride of platinum? These facts would have appeared to a chemist, at the commencement of the present century, totally inconsistent with what he knew of chemical action; but they are now readily comprehended, as results of laws which, being higher and more general than those previously known, include facts that at first sight appeared inconsistent with them. Unless, therefore, a *distinct* set of *laws* could be established, regulating vital affinities—which has not been accomplished or even attempted—we are scarcely justified in assuming that these laws may not be accordant with those which we recognise elsewhere.

165. There are still, however, many phenomena of inorganic chemistry which are as little understood as the operations of organic combination. To one class of these, attention has recently been directed by Berzelius.* In the usual operations of chemical affinity, where decomposition is effected by the interposition of a new agent, A, it is by the superior attraction of that agent for one of the elements, B and C, of the former combination. Thus, when sulphuric or any other mineral acid, A, is poured upon carbonate of lime, the carbonic acid, B, which was previously in combination, is liberated by the superior affinity of the new acid for its base, C; and the decomposing agent here enters into the new combination, A + C. But in the class of actions to which Berzelius has given the name of *catalytic*, a change is produced by one body, A, upon the composition of another, B + C, independently of any alteration or new combination of the first. Thus, the peroxide of hydrogen, which is readily decomposed by any substance having an affinity for oxygen, is also decomposed by some which themselves undergo no change, such as

* Edinburgh Philosophical Journal, vol. xxi.

the metals and the fibrin of blood; these produce in it a state analogous to fermentation, oxygen escaping, and water being left. Again, not only decompositions, but new combinations, may be effected in this manner. Thus, most metals at high temperatures, and platinum in a state of minute division at low temperatures, produce the union of oxygen and hydrogen in an explosive mixture. The action of sulphuric acid on alcohol in producing ether, without itself undergoing change, appears referable to the same class; as well as the conversion of gum or starch into sugar by the same agent (§ 350). We may consider it proved, then, that many substances possess the power of exercising upon compound bodies an influence essentially distinct from what is known as chemical affinity;—an influence which consists in the production of a displacement and new arrangement of their elements, without themselves directly participating in it. Assuredly such a power, which is capable of effecting chemical reactions in inorganic substances as well as in organised bodies, though still too little known to be accurately explained, must play a far more important part throughout nature than we have hitherto been led to suppose. "In defining it a new power," says Berzelius, with philosophic caution, "I am far from wishing to deny that some connection exists between its influences, and the electro-chemical ones with which we are familiar. On the contrary, I am very much disposed to recognise it as a peculiar manifestation of these same influences."

166. To whatever extent we may carry our views on this subject, there still remains a most extensive class of actions in the living organism, which must be regarded as essentially *vital*. In this class are comprehended the processes by which the peculiar compounds supplied by the operations of vital chemistry are converted into organised tissues, and endowed with properties that must be regarded as entirely distinct from any which are exhibited by inorganic matter. Nor is organisation confined to the solids alone, for traces of it may be detected in the fluids by which they are nourished; and these also exhibit properties which can scarcely be regarded as otherwise than vital (CHAP. VIII). What these properties are, will be a subject for future investigation. The most universal of them is that which is concerned in assimilating, organising, and communicating vital properties to nutritious matter, which each tissue converts into a structure like its own. To this property, the blood in animals, and the elaborated sap in vegetables, constitute, in the living state of these fluids, the appropriate stimulus; but the same materials, not themselves endowed with vital properties, would be totally inert. Every tissue possesses vital properties peculiarly its own, besides that which has been spoken of as common to all; and each property of each organ has stimuli appropriate to itself. Those which have a general action on the organism at large will be next pointed out, and their operation displayed.

CHAPTER II.

OF VITAL STIMULI.

167. It has been shown in the last Chapter, that all the actions manifested by living beings are dependent upon two conditions;—an organised structure possessed of certain properties which are termed *vital*, as being distinct from the physical properties of inorganic matter;—and certain agents whose presence is necessary to call these properties into operation, and thus to produce the manifestations of Life. We have seen that the knowledge of the Laws of Life, is simply that of its conditions expressed in their general and most comprehensive form; and it is obvious that all our acquaintance with the vital properties of the different tissues, must be derived from the extensive observation and accurate comparison of the actions they perform, when these dormant powers are called into play by their appropriate causes of excitement. Thus, a muscle is said to possess the property of *contractility*, because it exhibits evident contractions when acted upon by certain stimuli.

168. The study of the external conditions under which alone Life can be maintained, and of the influence of variations of these conditions upon its different actions, is, therefore, as essential a branch of the Science of Physiology, as the investigation of the structure and properties of the organism itself. But in tracing the connection of the different functions, it will be observed that these external agents are not the *only* vital stimuli, nor are they always the *immediate* sources of the excitement of the properties of the organism. For, in the higher classes of living beings at least, their influence is principally directed towards the preparation of a nutrient fluid, which contains the elements of all the solid tissues of the body, and the continued contact of which is necessary, not only to supply them with the materials of their growth and renovation, but to stimulate them to the performance of their respective actions. The original elaboration of this fluid, therefore, and the maintenance of it in its necessary purity, is the principal immediate effect of the external stimuli supplied by alimentary materials, heat, light, electricity, &c.; but the continued action of these is still required for the continuance of the vital operations to which it is subservient. In like manner, the elaboration of the nervous tissue out of the elements supplied by the blood in animals, gives rise to a new internal stimulus of a strictly vital character, —that by which the irritability of muscular fibre is excited, and those contractions thereby produced, which are not only essential to the exercise of the locomotive apparatus peculiar to this kingdom, but are also occasionally required for the maintenance of the organic functions (§ 31).

169. Besides the *vital* stimuli, the influence of which is necessary for the excitement and renovation of the properties of living bodies, there are

others which may produce an influence of a different kind, by calling into play the *animal* functions. Thus, the impressions made by various external objects upon the organs of sensation, give rise to a series of changes, which terminate in rendering the mind cognisant of the presence and characters of those objects; but this process is not directly connected with the maintenance of Life, and has, in fact, the same relation with the mental faculties of the being, which the effects of vital stimuli have to the properties of the corporeal structure. Nor can we regard other external agents, which occasionally operate on the living system, in the light of *vital* stimuli, since their action contributes nothing to the maintenance of the organic functions. The mode in which they produce their effects is, however, so analogous to that in which vital stimuli operate, that from their evident (because only occasional) action, a good illustration may be drawn of the more constant (and therefore less observed) influence of the latter. Thus, a pinch of snuff applied to the membrane lining the nostrils, *immediately* excites an increase in its secretions, adapted to defend it from the injurious contact; but it also excites impressions in the sensory nerves, which, conveyed to the central organs, may produce other changes, that terminate in the violent muscular action of sneezing. We shall hereafter see that the motion of the blood through the lungs is just as dependent upon its exposure to the influence of the air in the cells of those organs, as the action of sneezing is upon the stimulant applied to the nostril. The former, however, is a change of a vital character, being necessary for the continuance of other functions; the latter may be termed an accidental operation, and its connection with the maintenance of life is very remote.

170. The action of some of the *Vital Stimuli* will be most advantageously considered in connection with the functions to which they most directly minister; that of food, for instance, under the head of Absorption;* and that of air under the head of Respiration. Some general

* A curious example of the effect of food, not only in maintaining the existence and supplying the materials for the growth of the body, but in modifying its development, may, however, be best introduced here. In every hive of Bees, the majority of individuals consists of *neuters*, which have the organs of the female sex undeveloped, and are incapable of reproduction; that function being restricted to the *queen*, who is the only perfect female in the community. If by any accident the queen be destroyed, or if she be purposely removed for the sake of experiment, the bees choose two or three from among the neuter eggs that have been deposited in their appropriate cells, which they have the power of converting into queens. The first operation is to change the cells in which they lie into *royal* cells, which differ considerably in form, and are of much larger dimensions; and when the eggs are hatched, the maggot is supplied with food of a very different nature from the farina or bee-bread, which has been stored up for the nourishment of the workers, being of a jelly-like consistence and pungent stimulating character. After the usual transformations the grub becomes a perfect queen, differing from the neuter bee into which it would otherwise have changed, not only in the development of the reproductive system, but in the general form of the body, the proportionate length of the wings, the shape of the tongue, jaws, and sting, the absence of the hollows on the thighs in which the pollen is carried, and the loss of the power of secreting wax.

views on the influence of Heat, Light, and Electricity, will now be offered. Of all it may be observed, that the dependence of Life upon their *constant* influence is greater in proportion to the perfection of the structure, and the variety of its organs; and *vice versâ*. This is at once understood, when it is considered that the more developed are the individual parts of an organised system, the more close is the connection of its functions with one another (§ 15 and 153).

Of Heat as a Vital Stimulus.

171. All Vital action requires a certain amount of Caloric for its due performance, and can only continue within a particular range of temperature; between the limits of which, it is excited by the additional application of the stimulus, and depressed by its abstraction. But heat and cold are only relative terms; and as different vital actions may be carried on under various conditions as to temperature, the *amount of change* is found to have a greater influence on the function, than the absolute degree of caloric with which it may be in relation. Different species of animals and vegetables exhibit great varieties in the limitations of temperature which they require; and in their power of adaptation to extreme conditions. As a general rule it may be stated, that the greater the amount and variety of vital action, the more immediate is the dependence of the individual upon the maintenance of its usual temperature. We shall hereafter see (§ 479) that Plants are almost entirely dependent upon the medium they inhabit for the necessary supply of caloric, and that it is only during one or two periods of the existence of the more perfect kinds, that any sensible degree of heat is generated by them. But, being thus dependent, their vital actions are so adjusted as to be carried on within very wide extremes of heat and cold. Thus, a hot spring in the Manilla islands which raises the thermometer to 187°, has plants flourishing in it and on its borders. In hot springs near a river of Louisiana, of the temperature of from 122° to 145°, have been seen growing not merely Confervæ and herbaceous plants, but shrubs and trees. A species of Chara has been found growing and reproducing itself in one of the hot springs of Iceland, which boiled an egg in four minutes; and various Confervæ, &c. have been observed in the boiling springs of Arabia and the Cape of Good Hope. The most remarkable statement of vegetation at a very high temperature is given in Staunton's account of Lord Macartney's embassy to China. At the island of Amsterdam a spring was found, the mud of which, hotter than boiling water, gave birth to a species of Marchantia.

172. On the other hand, there are some forms of vegetation which only luxuriate in degrees of *cold* which are fatal to most others. Thus, the Lichen which serves as the winter food of the rein-deer, grows buried beneath the snow; and the beautiful little *Protococcus nivalis* or red snow

(Fig. 59) reddens extensive tracts in the arctic regions, where the perpetual frost of the surface scarcely yields to the influence of the solar rays at midsummer. To every species of vegetable there is a temperature which is most congenial, from its producing the most favourable influence on its general vital actions; and although many kinds of plants may be naturalised in climates very different from those in which they are indigenous, they generally exhibit some change in structure or mode of growth, conformable to their altered circumstances. "The various degrees of external temperature required by plants, are beautifully exemplified in mountainous districts, the low valleys of which are frequently adorned with the vegetable products of the torrid zone, and the more elevated districts with those of temperate climates, while towards the summit nothing is met with but the meagre natives of polar regions; and the lines of demarcation are sometimes so remarkable, that on the volcano of Teneriffe no fewer than five distinct zones, marked by the products which characterise different climates, are distinguished."*

173. The action of heat in directly stimulating the vital processes of Plants is very obvious. Its first effect is to increase the quantity of evaporation from the surface, and consequently the activity of absorption by the roots. The general processes of nutrition are thus carried on with vigour, so long as the plant is well supplied with water, which not only prevents its tissues from being dried up, but, by its conversion into vapour, moderates the temperature which would otherwise be excessive. But even then, if the heat continue violent, the growth of the plant is too luxuriant, and its energies are exhausted. If the supply of water is deficient, the development of the nutritive system is prevented, and the tissues are dense and contracted; thus, shrubs growing among the sandy deserts of the East have as stunted an appearance as those attempting to vegetate in arctic regions, their leaves being converted into prickles, and their leaf-buds prolonged into thorns instead of branches. Cold appears to act injuriously on plants, both by depressing the amount of their vital actions, and by the physical changes it produces. A very severe frost will sometimes congeal their juices, and burst the cells and vessels which contain them; but the viscidity of their fluids, and their distribution through minute tubes, tend to resist this injurious effect, which is also retarded by the slow conducting power of the wood. By these means, plants, which have little or no power of generating heat in themselves, are enabled to withstand, to a great degree, the influence of cold; and the dormant condition of their functions during winter, whilst itself partly a consequence of the depression of temperature, is also a provision appointed by Nature for the preservation of the vitality of the system. There is reason to believe that the injurious effect of excessive heat is sometimes manifested in a *physical* change, of a similar character to that just described as pro-

* Fletcher's Physiology, p. 100.

duced by cold. Grains of various kinds of corn will germinate after being exposed for a quarter of an hour to a temperature equal to that of frozen mercury; but their vitality is destroyed by exposure to water of 144°, or to vapour of 167°. At this temperature the structure of the seed undergoes a disorganising change by the rupture of the vesicles of starch which form a large part of it; and the loss of its power of germinating is therefore readily accounted for. Of the stimulating effects of heat upon the particular processes of the vegetable economy, more will be said under their respective heads.

174. Amongst the lower animals, the power of conformity to varieties of temperature is nearly as great as in the vegetable kingdom; and considering that the amount and variety of their vital actions may frequently be regarded as not surpassing that of plants, the absence of the capability of maintaining an independent temperature need not be a matter of surprise. The animals whose bodies appear most susceptible of enduring extremes of heat and cold, are chiefly those in which the nutritive or organic system predominates; for the full exercise of the animal powers a steadier temperature is necessary, and this is obtained by endowing the body itself with the means of generating warmth, and of resisting the violent action of external heat by refrigerating processes. By these means, animals of the highest organisation, such as man, are rendered capable of enduring vicissitudes of temperature, which would be fatal to many less perfect species; but the heat of his own body, which is that required for the continuance of its functions, varies extremely little. Hence it is seen that the degree of *external* heat or cold cannot always be taken as an indication of that which is compatible with the performance of the actions of life; since if a warm-blooded animal in a temperate atmosphere be deprived of its power of generating caloric, it will speedily become incapable of continued existence, even at a degree of external heat which is fully sufficient for the energetic life of tribes entirely dependent upon it. And, on the other hand, there are some species of cold-blooded animals, whose lives would be destroyed by a degree of heat which is but salutary to others, if their self-refrigerating power did not resist its influence. Thus, the muscular fibre of frogs is so easily excited that it would immediately pass into a state of permanent and rigid contraction, if bathed with a circulating fluid of the temperature of the blood of birds. But although a fluid medium of 104° is almost immediately fatal to these animals, they are capable of sustaining the same heat in air for a long time, without injury; as the rapid evaporation from their bodies resists its influence. Individuals of the human species have, in like manner, been subjected for a short time to a temperature of 260° in dry air, and for a longer period to a heat of 210° without much inconvenience; whilst exposure to watery vapour of 125°, or immersion in water of 113°, cannot be continued for many minutes.

175. Many facts are on record, however, which prove that vital action may continue under a very high degree of external *heat*, in animals which have no such power of modifying it; and which must always have an internal temperature bordering upon that of the medium in which they exist. It is with regard to Fishes, principally, that such observations have been collected. Thus, in the Manilla spring already mentioned, fishes were observed by Sonnerat; and in the thermal waters of Barbary, other species have been found existing at a temperature of 172°. Humboldt also mentions seeing fishes thrown up in very hot water from the crater of a volcano, which, from their lively condition, was apparently their natural residence. Various fresh water Mollusca are found in thermal springs, the heat of which is from 100° to 145°; and Rotifera and other animalcules, in water of 112°. Entozoa inhabiting the bodies of Mammalia, and of Birds, must of course be adapted to the conditions of their residence; and the heat which they there support, from 96° to 108° seems so natural to them that they become torpid in a cool atmosphere. On the other hand, the entozoa of cold-blooded animals seem capable of resisting not only cold, but heat; it has been stated that those inhabiting the intestines of a carp have been seen alive after the boiling of the fish for eating. With regard to the degree of *cold* which different species of animals are capable of enduring, information is still much wanting. It would appear probable that many, which have not at moderate temperatures the power of maintaining an independent heat, can generate caloric to sufficient extent to resist the influence of severe cold (§ 482). A large proportion of warm-blooded animals pass the winter in a state of hybernation (§ 156); and the non-conducting power of their coverings, and of the habitations they contrive for themselves, is generally sufficient to retain within their bodies the little heat which they then evolve. It is not a little curious that in such cases extreme cold acts as a temporary stimulus. If a dormouse or other hybernating animal, already reduced to torpidity by a moderate diminution of temperature, be exposed to a more intense degree of cold, its vital energies are aroused, as by any mechanical or other excitement; and it begins to execute the movements of respiration, by which its temperature is for a time elevated. But the cause which has aroused the activity of the animal is not adequate to maintain it. Too little heat is generated to enable it to resist for any length of time the continued depressing influence of the cold around it; in spite therefore of the renewed activity of the respiratory and circulating systems, the temperature of the animal quickly sinks, and he relapses into a lethargy which becomes fatal.

176. It is sufficiently evident, then, that there is an essential difference between the power of generating heat, and the power of sustaining variations in external temperature. The former is, in fact, possessed in the highest degree by those most deficient in the latter. It is greatest in

animals exhibiting the greatest extent and variety of vital action, and at the season when it is most required. We shall hereafter see that it depends on certain alterations in the nutritive system; and that it bears a constant relation with their activity (§ 494). The latter is a peculiar endowment varying in each species, and not manifesting itself by any discernible character of structure.

Of Light as a Vital Stimulus.

177. The influence of Light, as a stimulus to vital action, has been much overlooked. Its immediate effects upon the animal system are not so manifest as those of heat, but they are probably not less important. In the vegetable kingdom its mode of operation is less obscure; and the facility with which experiments may be performed regarding its action on plants, has led to a tolerably definite knowledge of its connection with their particular functions. It must be remembered that, like heat and cold, light and darkness are merely *relative* terms; and that in what appears a state of darkness to our senses, the influence of light may still exist, in a degree sufficient to excite the Vitality, if not the sensations, of other beings. The operation of Light is so closely connected with that of Heat, that it is not always easy to say what effects are due to one and what to the other. Means may readily be devised, however, of placing the subjects of experiment in the same circumstances as regards one of these agents, and of varying the amount of influence they respectively receive from the other.

178. There is scarcely a process in the Vegetable economy which does not depend upon the stimulus of light. The exhalation of vapour from the leaves, and consequent absorption of fluid by the roots,—the decomposition of the carbonic acid of the air, and the reception into the system of the carbon thus furnished,—the formation of the nutritious products adapted to the maintenance and extension of the structure,—and the elaboration of the peculiar secretions which are characteristic of different tribes, are so completely subservient to it, that they languish under a diminution, and cease entirely under a continued abstraction, of its agency. Nature has provided in the constitution of all living beings for the periodical changes which the alternation of day and night, and the succession of the seasons, produce in the degree of illumination afforded to them. We find some plants adapted only to exist where they can be daily invigorated by the powerful rays of a tropical sun; and others, whose energies, after remaining dormant during the tedious winter of the arctic regions, are aroused into a brief activity by the return of the luminary on whose cheering influence they depend. Neither race could flourish if transferred to the external conditions of the other; for to each are the circumstances of its existence natural, being adapted to its original constitution. To both is a certain amount of Light necessary,

though its distribution is so different. But there are some plants which seem able to flourish in a very feeble degree of illumination. Many Fungi are found vegetating in caverns and mines, to which no direct or reflected solar rays would seem to have access; and even more perfect plants have been seen growing under similar circumstances. Thus, Humboldt met with both Endogenous and Exogenous species, presenting a green colour, in the subterranean galleries of the mines of Freyberg; and the same circumstance has been stated to occur in some of the English Collieries.

179. When plants are subject to the influence of light in one direction only, they grow towards it, frequently in a manner remarkably differing from their usual form. The cause which so constantly produces this direction will be hereafter investigated; its object is evidently to enable the plant to avail itself as much as possible of its limited opportunities. The tendency of the roots, however, is to avoid the light; and the same tendency is exhibited by some of the simpler species of plants, to which the stimulus favourable to the growth of the more perfect would be excessive. Thus, many Mosses and Ferns are found growing only on the north and northwest sides of trees, hedges, and rocks. This is well exemplified by the Irish round towers, the north and north-western surfaces of which exhibit in many cases a luxuriant growth of cryptogamic vegetation, while the opposite parts are comparatively bare. It is well known that the Indians and backwoodsmen of North America, are frequently assisted in finding their way through the forest, by examining the trees, which indicate the north by means of the greater quantity of mosses, &c. which grow upon that side of the trunks. Many Lichens, again, are only to be found in the recesses of the most shady woods; and darkness (that is, a feeble degree of light,) is generally favourable to the growth of the Fungi. The periodical movements of the flowers of certain plants appear to be partly under the control of light, although without doubt subject to other influences. Some flowers open in the morning and close at evening; others, on the contrary, expand at night, and fold together early in the day. When withdrawn for a long time from the stimulus of light, these movements cease and the flowers remain closed; but by artificial illumination, they may be made to recommence; and Decandolle found that by preserving plants in a cellar, which was at night lighted with lamps, and by day kept dark, their natural times could be reversed. This, however, could only be effected when their original tendency had been subdued by the continued deprivation of the stimulus; and the experiment was not found to succeed with all vegetables.

180. There is one condition of plants in which the influence of light rather retards than hastens the progress of vegetation,—that, namely, of *germination* (§ 50). It will hereafter be seen, however, that this process

essentially consists in the conversion of the aliment stored up by the parent (in a form not liable to alteration from varieties of external condition), into a product fit for the nutrition of the embryo; and to the chemical process which this requires, light would be decidedly opposed, tending as it does to *fix* carbon in the system instead of favouring its liberation. As soon as this store is exhausted, and the plant has to maintain its own existence, the stimulus of light becomes necessary for the performance of its functions, as in other cases. A striking fact relative to the influence of this agent on the development of particular organs in the vegetable structure, has been brought forward by Mirbel. He found that up to a certain period of the growth of the little *gemmæ* of the Marchantia polymorpha (§ 61, Fig. 50), it appeared indifferent which side was uppermost; for that, on the surface of the foliaceous expansion exposed to the light, *stomata* (§ 429) would always be formed, while from the under surface, roots would be protruded. After the tendency to the formation of these organs had once been given, however, by a sufficiently protracted influence of light above, and of moisture beneath, it was in vain to attempt to alter it; for if the surfaces were then inverted, they would be restored to their original position by the twisting growth of the plant (Fig. 51).

181. Although there can be little doubt that Animals are equally dependent upon the influence of light with vegetables, the mode of its operation upon their vital fnnctions is not equally evident. As among plants, different tribes are adapted to maintain their existence under varying degrees of this stimulus. Most animals are intended by nature to pass the day in a state of activity, and to seek repose at night. There are some tribes, however, whose period of quiescence is that of light, and which go abroad to seek their subsistence in the evening twilight (such being called *crepuscular* animals), or at night. These are endowed with organs of vision capable of being stimulated by a much less degree of light than that which is necessary for human sight. Judging from the analogy of the eye, therefore, it is not difficult to understand, how an extremely low degree of this stimulus may be sufficient to maintain the existence of beings which are constitutionally adapted to it, when its more powerful action is required for others. Of the extent to which animal existence can be maintained under its complete deprivation, we have little certain information. It is well known that the solar rays, even when entering the water perpendicularly, are scarcely transmitted in any appreciable proportion beyond the depth of 100 fathoms. There is much reason to believe that the great majority of the inhabitants of the deep exist in the upper stratum, and that the dark and rayless abyss beneath is tenanted but by few living beings of any description. Of those which are occasionally fished up from great depths, it may be doubted whether they are constant or only temporary sojourners there. Captain

Scoresby mentions that various species of Star-fish, of the most brilliant and beautiful markings, were brought up at the end of a line of 250 fathoms; and Biot speaks of fishes whose existence has been ascertained at a depth of from 500 to 600 fathoms. There are very few exceptions to the fact, that the species of Mollusca captured alive have been taken at a less depth than 100 fathoms.

182. Various aquatic tribes seem to have their particular allotted range in the ocean, some being always found in very shallow waters, some in those of moderate depth, and others at a level considerably below them. The adaptation of their structure to particular degrees of *pressure* is remarkably shown by the distension (sometimes even to bursting) of the air-bladder of fishes brought up from a great depth to the surface; and as the relative quantity of light they receive in these different situations varies so much, there can be no doubt that each is susceptible of advantageous influence from the particular degree to which it is subject. That modifications of structure do take place in conformity with the degree of illumination in which the individual is to exist, is shown by the large size of the eyes in deep-water fishes,—evidently a provision for the collection of as many rays as possible, like the wide dilatation of the human pupil in a feeble degree of light. Among the lowest tribes of animals, there is evidently a susceptibility to the influence of light, where no special organs of vision are evolved. Some Polypes and Animalcules appear to seek, and others to shun it. But the actions performed by them for these purposes can scarcely be regarded as of higher character than the movement of plants in a particular direction, although we cannot as well trace the immediate channels of their excitement in the former case as in the latter.

183. Although the effect of light upon the functions of Animals is so little understood, there is no doubt that it exercises a marked influence upon the development of their structure. The appearance of animalcules in infusions of decaying organic matter is much retarded if the vessel be altogether secluded from it; and if equal numbers of silk-worms' eggs be preserved in a dark room, and exposed to common daylight, a much larger number of larvæ are hatched from the latter than from the former. The influence of light on animal development has been proved in the most striking manner by the experiments of Dr. Edwards. He has shown that if tadpoles be nourished with proper food, and exposed to the constantly-renewed contact of water (so that their branchial respiration may be maintained § 408), but are entirely deprived of light, their growth continues, but their metamorphosis into the condition of air-breathing animals is arrested, and they remain in the form of large tadpoles. Dr. E. also observes that persons who live in caves or cellars, or in very dark and narrow streets, are apt to produce deformed children; and that men who work in mines are liable to disease and deformity,

beyond what the simple closeness of the atmosphere would be likely to produce. It has been recently stated, on the authority of Sir A. Wylie, that the cases of disease on the dark side of an extensive barrack at St. Petersburgh, have been uniformly, for many years, in the proportion of three to one, to those on the side exposed to strong light. On the contrary, the more the body is exposed to the influence of light, the more freedom do we find, *ceteris paribus*, from irregular action or conformation. Humboldt has remarked that among several nations of South America who wear very little clothing, he never saw a single individual with a natural deformity; and Linnæus, in his account of his tour through Lapland, enumerates constant exposure to solar light as one of the causes which render a summer journey through high northern latitudes so peculiarly healthful and invigorating.

184. It is no argument against the inferences to be drawn from these facts, that we cannot understand the *mode* in which light thus influences the animal body. Peculiar sympathies are sometimes connected with its impressions on the eye. Thus, three cases are on record, in which the constant presence of light was necessary for the continuance of the respiratory movements even during sleep, so that the individuals woke in a state of dyspnœa if it were withdrawn;* and Dr. D. B. Reid has recently stated that in his experiments on respiration in noxious atmospheres, he found the unpleasant effects pass off more rapidly and completely, if he was exposed, not only to a fresh and free atmosphere, but also to a strong light.

Of Electricity as a Vital Stimulus.

185. The mode and degree in which this agent operates on the living system is one of the most obscure but most interesting questions in physiology. If, as has been stated (§ 18), there is reason to believe that all the new combinations of elementary substances which are formed in organised bodies, are held together by affinities of the same kind as those which operate in the inorganic world, namely, by electrical attraction, it is evident that Electricity must be regarded as one of the most important of all the Vital Stimuli, since upon its mode of operation will depend the character of all the earlier stages of the nutritive process. If this be the case, however, it would seem likely that all the electricity which is required is generated within the system itself; since the constant variations in the condition of the atmosphere would be attended with too much uncertainty of operation, were living beings dependent upon the electricity supplied by it. To the sources of the development of this agent within the system, allusion will hereafter be made (§ 496); at present the evidences of its operation when externally applied will be briefly enumerated.

* British and Foreign Medical Review, vol. v. p. 33.

186. It is well known that in all meteorological changes, alterations in the electric state of the atmosphere are largely concerned; and that the more decided the change, the more evident is the electric disturbance. Many vegetables seem very susceptible of such changes; some closing and others unfolding their flowers on the approach of a storm. In what is commonly spoken of as a highly electrical state of the atmosphere, young shoots of various plants have been observed to elongate with extraordinary rapidity. This effect, however, cannot be imitated by the artificial application of the stimulus; though a gentle current transmitted through the plant seems to increase the exhalation from its surface, and consequently affects other vital processes. It is not unreasonable to suppose, however, that as the different processes occurring in the system may require different degrees of the stimulus, that which is beneficial to some may be injurious to others, and hence that the economy in general may not be advantageously influenced. During the germination of the seed, however, the functions are of a much more simple and uniform character, being confined to the conversion of starch into sugar,—an essentially chemical change, which involves the liberation of a large quantity of carbonic and of some acetic acid. As all acids are negative, the seed, in rejecting them, may itself be regarded as in a negatively-electric condition; and accordingly it is found that the process of germination may be quickened by connection of the seed with the negative pole of a feeble galvanic apparatus, and retarded by a corresponding proximity with the positive.

187. With regard to animals, also, it may be stated, generally, that though Electricity seems to possess a peculiar relation with the organic processes, and to be capable of exciting certain of the animal properties (such as muscular contractility), no very definite influence seems to be produced by its external application upon the vital functions in their totality. Many tribes of animals appear to be peculiarly affected by changes in the electric condition of the atmosphere; and almost every human being must be in some degree cognisant of them by his own feelings. It will be only, however, when a much more accurate and extended series of observations shall have been made upon meteorological changes, and upon the contemporaneous actions of both vegetable and animal systems, that we shall have any means of forming definite conclusions upon this very perplexing subject. The destruction of Life by violent electrical shocks, is easily accounted for by the disturbance of the affinities between the component elements of the body, and the consequent immediate abolition of the vital properties of the tissues (especially of the *nervous*, which seems most affected by this agent), and this may take place without any *perceptible* change of structure. It is a well-known fact that the bodies of animals killed by lightning, or by an artificial discharge, pass more rapidly into putrefaction, than those of which life has

been destroyed by other ways; and it has been ascertained that the decomposition of flesh already dead may be hastened by electrifying it.

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188. Although the *pressure* of the surrounding medium can hardly be regarded in the light of a vital stimulus, yet it has so important an influence on the functions of life, that its operation must not be overlooked. The greater number of air-breathing animals are adapted to reside on the surface of the earth, subjected to the usual pressure of the air. Some, however, are habitually tenants of the higher regions of the atmosphere, and are constitutionally adapted to a greatly diminished pressure. It is probable that man, possessing as he does in so remarkable a degree the power of adaptation to external circumstances, could support life under any degree of rarity of the atmosphere which will maintain that of other vertebrated animals; but the rapid change from the ordinary pressure to one far less in amount, is usually accompanied in him, as in other animals (§ 550 *note*), with more or less disturbance of various functions. Some Birds, however, are so constructed as to be able to endure such sudden alterations without inconvenience; thus, the stupendous Condor of the Andes has been seen to dart from one of the highest peaks of Pinchincha to the very brink of the sea, thus traversing all climates in a few seconds, from a barometric pressure of 12 inches to one of 28. What has been said of the effects of change in the degree of atmospheric pressure, equally applies to the alterations resulting from depth of immersion in water. The superincumbent weight at 100 fathoms will be twenty times the pressure at the surface; and it is not to be wondered at, therefore, that the range of depth at which each species naturally exists, should be limited; but it is rather a source of astonishment that any should be capable of passing through so great an extent as facts show to be possible.*

189. There is another consideration relative to the nature of the surrounding medium which must not be overlooked. The saltness of sea water appears to act as a necessary stimulus to the vitality of the animals formed to inhabit it, and to be injurious to those which are accustomed to the contact of the pure element. Dr. Fleming has remarked that when a

* The whale, when harpooned or pursued by its enemies, dives to an immense depth. In some instances 1000 fathoms of line have been given out nearly perpendicularly. If attacked by a sword fish, he thus escapes from his pursuer; for the latter is unable to bear so great a depth, and waits at the surface for the rise of the whale to breathe. The monster is generally so disordered by the unnatural condition in which he has been placed, that when he comes within the reach of his enemies, he is easily despatched by them. In cases where, from the entanglement of the line, the whale has carried down a boat with him, the wood has been found, on his bringing it again to the surface, so much condensed and penetrated with fluid as to be no longer buoyant. "It may assist our comprehension" says Capt. Scoresby "of the enormous load the whale endures when it descends to the depth of 800 fathoms, to be informed that the pressure of the water on his body must sometimes exceed the weight of sixty of the largest ships of the British Navy, when manned, provisioned, and fitted out for a six months' cruise."

salt-water fish is put into fresh water, its motions speedily become irregular, its respiration appears to be affected, and, unless released, it soon dies; and that the same consequences follow when a fresh-water fish is suddenly immersed in sea-water. This is not the case with all fish, however; for there are many which, like the salmon, migrate periodically from rivers to the ocean, and return again. Moreover a cod will not only live but thrive well in fresh water, if properly fed; and fresh-water trout, in a healthy state, have been taken in the sea. In these cases the change was probably effected gradually.* Again, there are various littoral Mollusca which fix themselves to rocks at the mouths of rivers, in such a position that according to the state of the tide they will be immersed in water entirely fresh, or entirely salt, or in a mixture of both; and many of the purely marine species may be naturalised, like fishes, to a fresh-water existence, if the change be effected gradually.

CHAPTER III.

ON THE LAWS OF ORGANIC DEVELOPMENT.

190. There are few things more interesting to those who feel pleasure in watching the extraordinary advancement of almost every department of knowledge at the present time, than the rapid progress of philosophical views in sciences which have hitherto been confined too much to mere observation. The laws of Life were long considered beyond the reach of human investigation, and the mind shrunk from attempting to analyse the various phenomena which, though constantly under observation, must be reduced to their simplest form before any inductive reasoning can be founded upon them. It is recorded, however, of Newton that, whilst contemplating the simplicity and harmony of the laws by which the universe is governed, as manifested in the relations which his gigantic mind developed between the distant and apparently unconnected masses of the planetary system, his thoughts glanced towards the organised creation; and reflecting that the wonderful structure and arrangement which they exhibit, present in no less a degree the indications of the order and perfection which can result from Omnipotence alone, he

* My very intelligent friend, Mr. S. Stutchbury, the Curator of the Bristol Institution, has informed me that in some of the South Sea Islands it is a common practice of the natives, at the season when fish are most abundant, to drive them from the sea into some of the long narrow inlets which abound on their coasts; and then, after securing the entrance by a bank of stones, to turn a rivulet into this semi-artificial reservoir, so as to maintain a continual current of water, and thus to preserve for the tables of the chiefs a supply of fish when it would otherwise be out of season. In this case, also, the change from salt to fresh water will of course be gradually effected, and, in fact, will never be quite complete, as the reservoir still possesses a slight communication with the ocean.

remarked, "I cannot doubt that the structure of animals is governed by principles of similar uniformity." ("Idemque dici possit de uniformitate illâ, quæ est in corporibus animalium.") "Why," asks Cuvier in his eloquent discourse on the revolutions of the globe, "should not Natural History some day have its Newton." Although the labours of the Naturalist and Comparative Anatomist have not yet established laws of the *highest* degree of generality,—the discovery of which *may* perhaps be reserved for another Newton,—many subordinate principles have been based on a solid foundation, and many more, which were at first doubtful, are daily receiving fresh confirmation. Several of these laws are alike important from their extensive range, and interesting from the unexpected nature of the results to which they frequently lead; and though their application may sometimes appear forced, and inconsistent with the usual simplicity of nature, further investigation will generally show that the difficulty is more apparent than real (frequently arising solely from our own prejudices), and that it is in many cases the result of the combination of unity and variety, by which is produced the endless diversity united with harmony of forms so remarkable in the animated world.

191. In comparing phenomena of any kind for the purpose of arriving at a law common to them all, it is necessary to feel certain that they are of a *similar character*. Indeed the sagacity of the philosopher is often more displayed in his discovery of that similarity amongst his facts which allows of their being compared together, than in the inferences to which such comparison leads him. The brilliancy of Newton's genius was shown in the perception that the fall of a stone to the earth, and the motion of the moon around it, were *analogous* phenomena, subject to the same law; not in the mere deduction of the numerical law from the ratios supplied by those facts. In the sciences which have Life for their subject, the dissimilarity of the facts which are made the object of comparison, often prevents the true relation between them from being readily detected. Here it is that the mental training which the previous cultivation of Physical science affords, becomes peculiarly valuable to the Physiologist. "The most important part of the process of induction," says Professor Powell,* "consists in seizing upon the probable connecting relation, by which we can extend what we observe in a few cases to all. In proportion to the justness of this assumption, and the correctness of our judgment in tracing and adopting it, will the induction be successful. The analogies to be pursued must be those suggested from already-ascertained laws and relations. This, in proportion to the extent of the inquirer's previous knowledge of such relations subsisting in other parts of nature, will be his means of guidance to a correct train of inference in that before him. And he who has, even to a limited extent, been led to observe the connexion between one class of physical truths and another,

* Connexion of Natural and Divine Truth, p. 33.

will almost unconsciously acquire a tendency to perceive such relations among the facts continually presented to him. And the more extensive his acquaintance with nature, the more firmly is he impressed with the belief that some such relation must subsist in all cases, however limited a portion of it he may be able actually to trace. And it is by the exercise of unusual skill in this way, that the greatest philosophers have been able to achieve their triumphs in the reduction of facts under the dominion of general laws."

192. If, as was formerly stated (§ 3), the true objects of Physiological investigation are only now beginning to be understood, it is no less certain that the true method of pursuing them has not long been followed. From the time of Aristotle downwards to the commencement of the present century, anatomists have been in the habit of regarding similarity of external form and of evident purpose, as indicating the analogies between different parts. Now, however, they are aware of the necessity of resting their comparison upon the elementary structure of the organs, their connections with each other, and the changes which they undergo during the progress of their development. Neither of these grounds of judgment can be trusted to alone: but when combined with each other, they leave no room for hesitation in the belief that an analogy may exist, where diversity in function and external form would forbid us to seek for it; or, on the other hand, that it is really wanting, where the apparent similarity would lead us to anticipate it.

193. If, for example, we take a cursory glance at the organs of support or motion in the air with which different animals are furnished, we shall observe a community of function, and a general similarity of external form; concealing a total diversity of internal structure and of essential character. Amongst all the classes which are adapted for atmospheric respiration, we encounter groups of greater or less extent, in which the resistance of this element becomes the principal means of progression; and even among aquatic animals, there are many instances in which the function of locomotion is partly dependent upon the same agent. Wherever *true wings* exists among the Vertebrata, some modification of the anterior member serves as their basis; but there is considerable variety in the mode in which the apparatus is constructed. Thus, in the Bat, the required area for the surface of the wing is formed by an extension of the skin over a system of bones, of which those of the hand form a very large part; and this membrane is extended also from the posterior extremity, and attached to the whole length of the trunk as well as to the tail, where one exists. In the Bird, on the contrary, the wing is formed by the skin and its appendages (§ 39) attached to the anterior member alone; and here the bones of the hand are developed in a comparatively slight degree, those of the arm and fore-arm being the principal support of the structure. From what is preserved of the Pterodactylus,

it seems that the wing of this extraordinary animal was extended, not over the whole member, as in the Bird,—nor over the hand, as in the Bat,—but over one of the fingers only, which was immensely elongated in proportion to the rest. In the Flying-fish, again, the pectoral fins may be regarded as, in some sort, its wings; though it does not appear that the animal has the power of raising itself by means of their action on the air, the impulse being given at the moment of quitting the water. These fins are distinctly analogous to the anterior members of higher Vertebrata; but the bones of the arm and fore-arm are scarcely developed, while the hand is expanded, and joined immediately, as it were, to the trunk.

194. A very different structure prevails among those imperfect wings, which serve rather to *support* the animals which possess them, in their movements through the air, than to propel them in that medium. Thus, in the Flying Squirrels, Flying Lemurs, and Phalangers or Flying Opossums, there is an extension of the skin between the fore and hind legs, which, by acting as a parachute, enables the animals to descend with safety from considerable heights. In the Draco Volans, on the other hand, the wings are affixed to the sides of the back, being supported by prolongations of the ribs, and are quite independent of the extremities. Here we have still the same function and general form; but it would evidently be absurd to say that the organs are of the same real character. Among the Invertebrated classes, there is still greater variety in the construction of the organs which make use of the resistance or impelling power of the air as a means of locomotion. Details on this subject have already been given in various seetions of the Introduction; but in addition to what was there stated regarding the wings of Insects, it may be mentioned that there seems now sufficient reason to regard them as appendages to the respiratory system.*

* That they bear no real analogy to the wings of Vertebrata, would appear almost self-evident, when their structure is compared; and yet there are Entomologists who have maintained that the wing of an Inseet is a modification of its leg. A very little attention to the relative positions of these parts and the history of their development, will disprove this doctrine; whilst the true nature of the wing will be stated in its proper place (§ 398). Any one who compares the skeleton of the wing of a Bat or Bird with that of the fore-leg of a terrestrial quadruped, will see an obvious analogy in the essential parts of whieh each is eomposed, every bone which exists in one being discoverable (though not always in a separate form) in the other; whilst few unprejudiced persons could trace in the minutely-ramified nerves which support an insect's wing, any resemblance to one of its simply-articulated members. The segments whieh form the body of a caterpillar never possess more than one pair of legs on each; but towards the latter period of their Larva eondition, the rudiments of the wings may be detected beneath the skin, and these beeome more evident in the Pupa. When the perfeet insect emerges, it is found that only three pairs of legs are retained by it, these being attached to the three segments of the thorax, whilst the nine segments of the abdomen have lost all trace of members. It is to the second and third segments of the thorax that the wings also are attaehed. Now if these wings had taken the place of the legs whieh disappear during the metamorphosis, there might have been some ground for regarding them as analogous organs; but if their *position* be fairly considered, a resemblance which is at best so obseure must be

195. These instances will show the caution which must be exercised in deciding upon analogies between organs, from correspondence in external form and function merely. Many similar ones might readily be adduced from the animal kingdom; but the vegetable world affords them in even greater abundance. To take a very simple case;—the *tendril* is an organ developed to serve a particular purpose, that of supporting the plant by twining round some neighbouring prop; but this varies much in its real character, being in the Vine a transformation of the peduncle or flower-stalk, in the Pea a prolongation of the petiole or leaf-stalk, in Gloriosa the point of the leaf itself, whilst in the singular genus Strophanthus it is actually the point of the petal which becomes a tendril and twines round other parts. But it is now time to speak of the other class of instances, in which a real similarity of character is concealed under a marked difference of form, and even of function. Of this, the Respiratory apparatus affords an excellent illustration. Few uninstructed observers would perceive any resemblance between the gills of a fish and the lungs of a quadruped, or between the elegant tufts on the body of a sand-worm, and the air tubes ramifying through the structure of an insect; and those who are in the habit of forming exclusive notions upon a hasty survey, might be led to deny that any real analogy could exist. When the character of the function is investigated, however, with the structure it requires for its performance, it becomes evident, that in order to bring the circulating fluid into the due relation with the atmosphere, all that is needed is a membrane which shall be in contact with the air on one side and with the fluid on the other. And this key, applied to the examination of all the forms of respiratory apparatus which exist in the animal kingdom, shows that they all possess the same essential character, and that their modifications in particular instances (which will hereafter be specially described, CHAP. IX.) are only to adapt them to the conditions of the structure at large. It has been seen that in one case, that which is obviously a part of the respiratory structure is made subservient to the function of locomotion; and in the swimming-bladder of fishes, which is now certainly ascertained to be a rudimentary lung (§ 406), we have a still more remarkable proof of the necessity of disregarding function in investigations of this kind. In Vegetable Physiology, again, innumerable instances of the same kind might be adduced, from amongst the ever-varying forms which the same elements assume in the leaves and flowers; but these must suffice for the present purpose.

196. The most general, then, of all the laws which have been yet discovered to regulate the structure of organised beings, is founded upon

abandoned. On attending to their evolution also, it is found that in their early condition they evidently form part of the respiratory system, and are developed at the same rate with it, being only fully expanded at last, after their tubes have been forcibly distended with air (§ 396); and that in some aquatic insects, they actually serve as gills during the larva state.

the careful study of these analogies; and is commonly denominated the law of *Unity of Composition.* It is important to state this law in an unexceptionable form, since much objection has justly been made to that in which it has been propounded by some physiologists. It may, however, be remarked *in limine* that, for the broad acceptation in which it will be here explained, a strong argument of an *a priori* character may be adduced. If it be admitted as a principle every where prevailing throughout creation, that every *end* is attained by the best adapted *means* (a principle which not only revelation but reason in every way supports), it will necessarily result that, where the function or purpose is identical, the structure of the organ by which it is to be performed should be always essentially the same, but that the disposition of its parts should vary with the circumstances in which that function is to be performed. It is to the *apparent* alterations which result from these diversities in arrangement, that the observations of those writers apply, who have traced in them the indications of Omnipotent control over the elements employed. Thus, in the words of Richard Baxter, "Art and means are designedly multiplied that we might not take it (the order of creation) for the effect of chance: and in some cases the method itself is different, that we might see it is not the effect of surd necessity." And in the same excellent spirit it has been remarked by a modern writer, that "a certain definite mode of being is generally adapted to a certain definite end. But no absolute necessity binds the means to the end. The mode generally adopted may be, and doubtless is, the best; but the varieties of modes adapted to similar conditions demonstrate that the end has not influenced and controlled the contriving and adapting power which might have chosen another mode, and which does occasionally adapt widely different modes to the same purposes."* A deeper enquiry into the subject will show us, that there is everywhere a *fundamental unity* prevailing through all the varieties of any particular structure; and it need scarcely be ~~be~~ argued that the original employment of a means which should be capable of modification so as to suit every end, implies at least as high a degree of Creative Wisdom and Power, as the creation of *new* means in particular cases to which the plan first adopted might prove inapplicable.

197. It is necessary to bear in mind that the law of Unity of Composition applies in its most general sense to the organic systems only, and does not embrace the locomotive and sensorial organs with these. It is obvious that this must be the case, since Plants are entirely deficient in the structures composing the latter; and it is to be recollected also that these organs are not destined to produce any immediate change in the composition or state of the individual (except so far as regards his psychical condition), and only influence his relation with the external world. But it will be found that the same principle taken in a more restricted

* Duncan on Analogies, p. 25.

sense applies to these organs also; since, although the locomotive apparatus varies so much in the different classes of animals, its essential characters are the same throughout each of the principal groups into which the kingdom may be divided. *Throughout the whole animated Creation, then, the essential character of the organs which all possess in common, remains the same; whilst the mode in which that character is manifested varies with the general plan upon which the being is constructed.* Thus, in the lowest plants, as in the embryo-state of animals, the whole surface is modified for absorption of nutrient fluid; and the only change in the character of this absorbent surface in the higher vegetables consists in its restriction to a certain part of the structure, the root, which is developed so as to bring it into most advantageous employment. In animals, a change of a different character has become necessary to adapt the function to the conditions of their being; and we find the absorbent points distributed not upon the external surfaec, but upon an inversion of it, adapted to retain and prepare the food (§ 237). Still the same fundamental unity exists; and the spongiole of the vascular plant, and the origin of the absorbent vessel in the animal, have precisely the same essential character with the membrane which constitutes the general surface of the Sea-weed or Red Snow. The advance from the lowest to the highest form in each kingdom is extremely gradual, as will be hereafter shown (CHAP. V.); and it will also appear that there are links of connection between the two principal modifications of the structure, a plant exhibiting something like the digestive cavity and absorbent system of the animal (§ 239), and certain animal forms absorbing from their general surface like the lowest plants.

198. This law may be applied, not only in the general method just pointed out, but in more restricted cases. Thus, where a particular function is performed on two or more different plans, it will be found that each is steadily followed out through a number of varying circumstances, with such modifications only as may be necessary to adapt it to them. Throughout the Vegetable Kingdom for example, we observe the absorbent surface external, and among Animals internal. In aquatic animals again, we find the respiratory surface prolonged externally into gills; whilst in the air-breathing classes it is extended internally, so as to form tubes or cells exposing a large amount of surface. In the flowers of Phanerogamia, a certain number of different organs may fairly be regarded as universally present, either in a developed or rudimentary condition; and in the osseous skeleton of Vertebrated animals there is, in like manner, a correspondence of essential and even of subordinate parts. We do not find, in making such comparisons, that when any new modification of the function is to be performed, a structure entirely new is provided for it; for the end is always attained by a corresponding modification in the structure already present. Thus, where a plant requires the means of retaining fluid for absorption, a pitcher is provided by the metamorphosis

of the leaf; and where a bird has to be endowed with powers of flight, a wing is constructed out of its anterior member.

199. Every organ, therefore, which has a fundamental type common to all animated beings, has also a more special type possessed by each of the great classes into which they may be divided. And those organs which are restricted to certain divisions of either kingdom, have types peculiar to the various classes in which they appear. Thus, the organs of support and protection which constitute the skeleton, are external throughout the sub-kingdoms Mollusca and Articulata, exhibiting an approach, however, in their highest forms, to the internal position which they occupy in Vertebrata. In the latter division, the spinal column and its appendages, which essentially constitute the osseous skeleton, undergo many remarkable modifications, none of which, however, obscure the original type. Thus, the skull is but an expansion of the three highest vertebræ, in order to afford space for the development of the contained brain, and of the organs of sense; and however strange such a statement may appear to those who are only acquainted with the skull of man, the fact is evident where the brain is little developed, as among fishes and the lower reptiles. On the other hand, the tail is a continuation of the vertebral column, generally deprived of some of its parts, and often having several of its joints consolidated, as in the human sacrum and coccyx. Where no members appear, as in serpents, some rudiments may often be traced, although totally inapplicable to the purpose of locomotion, as in the slow-worm, and the boa. It is a most beautiful exemplification of this law of uniformity of composition, combined with the one which will be next stated, that we never find any organ *totally* absent, which is possessed in a prominent degree by the members of adjacent groups. Thus, the rudiments of teeth, which are never developed, and at a later period cannot be detected, are found in the embryo of the whale, and are also observed during the development of the jaws of many birds. In the abdominal muscles of the Mammalia are found white cartilaginous lines, indicating the situation of the abdominal sternum and ribs of Lizards, of which these lines are the representation; still it is not impossible that they may serve the purpose which has been attributed to them,—that of preventing the contraction of the whole length of those muscles into a knot, which might press injuriously on the viscera. It is by no means uncommon for an organ to serve, in the lower stages of its formation, a purpose quite different from that of its perfect form; thus, the swimming bladder of a fish is a rudimentary lung, but instead of being subservient to respiration, it ministers to an entirely different function.

200. Connected with this law is that of *Progressive Development.* In the early stages of formation in every animal or vegetable, we may observe as great a dissimilarity to its ultimate condition as exists between

the lower and higher members of each kingdom. And if we watch the progress of evolution, we may trace a correspondence between that of the germ in its advance towards maturity, and that exhibited by the permanent conditions of the races occupying different parts of the ascending scale of creation. This correspondence results from the operation of the same law in both cases. If we compare the forms which the same organ presents in different parts of the series, we shall always observe that it exists in its most general or diffused form in the lowest classes, and in its most special and restricted in the highest, and that the transition from one form to the other is a gradual one. Thus, to refer again to the organs of absorption;—these we find diffused over the whole exterior in the simplest plants and animals, so that the surface becomes, as it were, *all root;* whilst they are restricted to a very small proportion of it in vascular plants, and in the higher animals. The function, therefore, which was at first most general, and so combined with others performed by the same surface as scarcely to be distinguishable from them, is afterwards found to be confined to a single organ, or *specialised* by separation from the rest; these having, by a similar change, been rendered dependent on distinct organs. It follows, therefore, that there is a greater variety of dissimilar parts in the higher organisms than in the lower; and hence the former may be said to be *heterogeneous*, whilst the latter are more *homogeneous*, approaching in some degree the characters of inorganic masses. This law is, therefore, thus concisely expressed by Von Bär, who first announced it in its present form. "*A heterogenous or special structure arises out of one more homogeneous or general; and this by a gradual change.*" The details which will be given in the second division of this work,—relative to the evolution of structure and the complication of function, witnessed in studying the development of each system, both in the ascending scale of creation, and in the growth of the embryo,—will so fully illustrate this law that more need not here be said of its application.

201. This law holds good with respect to *function* as well as to *structure;* indeed it must inevitably do so, since all alteration in structure must be accompanied with more or less change in its properties. But observation of the functions of the more complex forms of animated beings leads to the knowledge of another law, which in some degree restricts the operation of the one just mentioned. It may be stated as follows.—*In cases where the different functions are highly specialised, the general structure retains, more or less, the primitive community of function which originally characterised it.** As this law also will be copiously illustrated in subsequent chapters, it is unnecessary here to do more than point out its mode of application. The absorbent system has been shown to be one of those most highly specialised (or, in other words, having a

* See Edinburgh Philosophical Journal, July, 1837.

separate organ most exclusively devoted to it) in the more complex organisms; yet it is never entirely restricted to its special organ. For, as in the simplest or most homogeneous beings the entire surface participated equally in it, so in the most heterogeneous every part of the surface retains some connection with it; since, even in the highest plants and animals, the common external integument admits of the passage of fluid into the interior of the system, especially when the supply afforded by the usual channels is deficient. In the same manner we find that, whilst in the lowest animals the functions of excretion are equally performed by the whole surface, there is in the highest a complicated apparatus of Glandular organs, to each of which some special division of that function is assigned; but as all these glands have the same elementary structure, and differ only in the peculiar adaptation of each to separate a particular constituent of the blood, it is a necessary result of the law just stated, that either the general surface of the skin or some of the special secreting organs should be able to take on, in some degree, the function of any gland whose duty is suspended; and observation and experiment fully bear out this result, as will hereafter appear (CHAP. XI).

202. Allusion was just now made to the correspondence which is discernible between the transitory forms exhibited by the embryos of the higher beings, and the permanent conditions of the lower. When this was first observed, it was stated as a general law, that all the higher animals in the progress of their development pass through a series of forms analogous to those encountered in ascending the animal scale. But this is not correct; for the *entire animal* never does exhibit such resemblances, except in a few particular cases to which allusion has already been made (§ 80); and the resemblance or analogy which exists between individual organs has no reference to their *forms*, but to their *condition* or *grade of development*. Thus, we find the heart of the Mammalia, which finally possesses four distinct cavities, at first in the condition of a prolonged tube, being a dilatation of the principal arterial trunk, and resembling the dorsal vessel of the Articulated classes; subsequently it becomes shortened in relation to the rest of the structure, and presents a greater diameter, whilst a division of its cavity into two parts, a ventricle and an auricle, is evident, as in Fishes; a third cavity, like that possessed by Reptiles, is next formed, by the subdivision of the auricle previously existing; and lastly a fourth chamber is produced by the growth of a partition across the ventricle; and in perfect harmony with these changes are the metamorphoses presented by the system of vessels immediately proceeding from the heart. In like manner, the evolution of the brain in man, is found to present conditions which may be successively compared with those of the Fish, Reptile, Bird, lower Mammalia, and higher Mammalia; but in no instance is there an exact identity between any of these.

203. Since the doctrine, so far as it is correct, refers to individual organs alone, and not to those collections of them which go to form living structures, it is no objection to it to say, as may be fairly done, that neither the embryo of man, nor that of any other among the higher animals, resembles a lower animal to such a degree as to be mistaken for one; for, however similar may be the apparent origin of each being, the changes which it undergoes from its very commencement have a definite end,—the production of its perfect and specific form. Such an admission, therefore, can have no tendency to confound the established distinctions in Natural History. But this correspondence may, as already stated, be regarded in the light of a result or corollary from the more comprehensive law at first laid down; since, if the evolution of particular organs discloses the same plan, when traced upwards from their simplest and most general forms,—whether in the lowest being, or in the embryo of the highest,—their progressive stages must present resemblances in condition. As already mentioned (§ 80), there are certain cases in which the limitation is removed, and the whole being is made to correspond in what must be regarded as its embryo condition with the form and structure characteristic of an inferior class. This is for the purpose of enabling it to maintain its own existence at an earlier period than would otherwise be practicable; and the means by which this is effected without the addition of any new structure, or the infraction of any law of development, are not a little curious. Thus, to adapt the embryo frog to the life of a fish, requires a provision for aquatic respiration; and this is made simply by developing to a greater extent in the tadpole, those rudiments of gills which all the higher animals possess in common with it. In the Larva of the insect, again, which, at its emersion from the egg, bears so small a proportion to its ultimate magnitude (§ 231), the *germinal membrane*, that in other ova is spread over and progressively absorbs the yolk or store of nutriment supplied by the parent (§ 534), speedily becomes a large intestine, into which the food is taken in prodigious quantities by the mouth: and when it has served this purpose, a part of it is metamorphosed into generative organs, which in the perfect Insect are destined to continue the species, and which are elaborated in other animals from the same source—the germinal membrane—before their first entrance into the world. In the form in which the law of progressive development has been here stated, it will be found applicable to the Vegetable kingdom, as well as to the animal; the progress of individual organs from a more general to a more special type, being discernible as well in the development of the embryo as in ascending the scale. But it would be quite impossible to maintain the position that any of the stages of growth presented in the evolution of a flowering plant, are *altogether* comparable with the permanent forms exhibited by Lichens, Fungi, Mosses, &c.

204. Another law, of less comprehensive application, has been established by the study of the evolution of the higher organisms, and is called that of *excentric development.* It is observed that the parts of the structure most distant from the median plane, are in general more advanced than those nearer the centre; thus, the ribs are ossified earlier than the sternum or vertebral column,—the parietal bones sooner than the central portions of the sphenoid or occipital. But it appears to have a more extended application than this; for there is much evidence to prove that the formation of *all* the organs in Vertebral animals takes place on a double system, not only those which are permanently double being thus evolved, but those which subsequently appear as single and even asymmetrical organs consisting, at an early period, of two separate and equal halves. Thus, the spinal column and all the bones placed on the central line, are originally divided longitudinally, the points of ossification not being on that line, but on each side of it; in some of the lower animals, the lateral halves remain separate, as in the case of the lower jaw of most serpents; and in man it is not uncommon to find a permanent division in particular bones, especially the frontal, which can scarcely be regarded as amounting to a malformation. But the application of this law is still more extraordinary, when it is considered in relation to organs which in their perfect form are not only single, but are placed off the median plane of the body, so as not to consist of two equal halves. The liver, for instance, is almost entirely confined in adult man to the right side of the body; but in the fœtus, its two lobes are at one period equally balanced between the two (§ 139). The heart is, at its first formation, placed on the median line, as in the Articulata, and consists of two equal halves; while the large vessels connected with it, the aorta and vena cava, are actually double. Many similar instances might be adduced; but those afforded by *monstrous* conditions, or *malformations* are most illustrative.

205. Of the malformations which occur in the higher animals, a great variety may be referred to *arrest of development;* and this may operate in several ways. It leads to the permanent assumption of a condition, in particular organs, which should have been transitory only; and thus a resemblance will arise between the condition of that organ in the malformed being, and that which is characteristic of some inferior grade. This is peculiarly striking in the malformations of the circulating system, of which many instances will hereafter be adduced. But it may also present itself in a deficiency of structure on the median line, such as occasions hare-lip, cleft palate, bifid uvula, absence of the commissures of the brain, approximation of the two eyes in one socket, the disease termed *spina bifida* (which results from deficiency of the posterior part of the rings of the vertebræ), and many others. These and other deformities are no longer regarded by the philosophic anatomist with the horror and disgust which they once inspired, and which they still excite in the vulgar

mind; since they afford the most appropriate and convincing evidence of the Uniformity of design which runs through creation; and, if properly employed, become the most stable foundation for the prosecution of the enquiry into the laws through which that Design has operated.

206. In the Vegetable kingdom, the study of monstrosities has been peculiarly effectual in the elucidation of the laws regulating the metamorphoses of organs, or the dissimilar forms which the same elements may assume. Thus, it is found that parts of the flower which have, in their ordinary state, least of the foliaceous appearance, such as the stamens or carpels, revert to the form of leaf (which may be regarded as the type of them all), under some alteration in the conditions of their development, which is not yet fully understood. Again, the forms of flowers, which in some species are characteristically deficient in symmetry, exhibit a tendency to assume that regularity which may be regarded as typical of the structure. Thus, the common Snap-dragon has an irregular form of corolla, which is denominated *labiate*, from the two large lips bounding its mouth, and is furnished with a single long spur; it is by no means uncommon, however, to find specimens in which the corolla has become perfectly regular, each petal being similar in form, and each furnished with a spur. At the same time, the stamens, which in this species are four and *didynamous* (two long and two short), become five, and all of the same length; and it is thus shown that the suppression of one stamen and the shortening of two others, which is characteristic of this group, does not result from any essential alteration in the plan of structure, but merely from a deficiency in the evolution of certain parts of which the rudiments exist. In the Nasturtium, again, which in its usual state possesses one spurred petal only, the tendency to regularity is exhibited, sometimes by the disappearance of the spur, sometimes by the development of it on other petals. Innumerable examples of the same kind might be adduced; but these are sufficient to prove the importance of attention to them.

207. Another subordinate law, which however has an extensive application, is that of the *balancing of organs*, alluded to by Paley and other authors as the "principle of compensation." This, like other generalisations, has been carried too far by many writers who have dwelt upon it. Thus, it has been stated in the following most objectionable form;—that the extraordinary development of one organ *occasions* a corresponding deficiency in another, and *vice versâ*. It is perfectly true that in a great majority of cases *the extraordinary development of one organ is accompanied by a corresponding deficiency of development in another;* but the development and the deficiency are both parts of one general plan, and neither can be regarded as the cause or the effect of the other. Thus, in the human cranium, the elements which form the covering or protection of the brain are very largely developed, whilst those which constitute the face are comparatively small. In the long-snouted herbivorous quadru-

peds or reptiles, on the other hand, the great development of the bones of the face is coincident with a very small capacity of the cerebral cavity. In the bat, we find the anterior extremity widely extended, so as to afford to the animal the means of rising in the air; whilst the posterior is very much lightened, so as not to impede its flight. In the kangaroo, on the other hand, the posterior members are very large and powerful, enabling the animal to take long leaps; whilst the fore paws are proportionably small. The mole, again, requires for its underground burrows the power of excavating with its fore-feet, whilst the hind legs are used for propulsion only; and the relative development of these members follows the same proportion as in the bat, although the *plan* in the two cases is widely different. Moreover it is obvious that, from the peculiar habits of this animal, eyes would be of little or no use to it; and accordingly we find them merely rudimentary, and no cavity in the skull for their reception; whilst to compensate for the want of them, the ethmoid bone, which contains the organ of smell, is amazingly developed. In other classes of animals similar illustrations abound; and the relation between the internal and external skeletons, already alluded to (§ 82), is a striking proof of the extensive application of this principle.

208. Another law, propounded by Cuvier, and supported by other authors, is that of the *harmony of forms*, or the *coexistence of elements*. It implies that there is a specific plan, not only for the formation, but for the combination of organs; that there is a constant harmony between organs apparently the most remote; and that the altered form of one is invariably attended with a corresponding alteration in the others. That this statement is true as far as it goes, no one can deny; and the researches which have been based upon it have been most successful in repeopling the globe, as it were, with the forms of animals which have long been extinct, but which can be certainly predicated even from minute fragments of them. A general comparison of the skeleton of the carnivorous with that of a herbivorous quadruped, will show the manner in which this enquiry is pursued. The tiger, for example, is furnished with a cranial cavity of considerable dimensions, in order that the size of the brain may correspond with the degree of intellect which the habits of the animal require. The face is short, so that the power of the muscles which move the head may be advantageously applied. The front teeth are large and pointed; and by the scissors-like action of the jaw, they are kept constantly sharp. The lower jaw is short, and the cavity in which its condyle works is deep and narrow, allowing no motion but that of opening and shutting; the fossa in which the temporal muscle is imbedded, is very large; and the muscle itself is attached to the jaw in such a manner as to apply the power most advantageously to the resistance. The molar teeth are sharp and adapted for cutting and tearing only. The spinous processes of the vertebræ of the back and neck are very strong and

prominent, giving attachment to powerful muscles for raising the head, to enable the animal to carry off his prey. The bones of the extremities are disposed in such a manner as to allow the union of strength with freedom of motion; the head of the humerus is round, and the fore-arm has the power of pronation and supination, indicated by the character of the articular surfaces. The toes are separate, and armed with claws, which are retracted when not in use by a special apparatus that leaves its mark upon the bones.—On the other hand, in the conformation of the herbivorous quadruped, we are at first struck with the diminished capacity of the cranium, and the size of the bones of the face. The jaws are long, and have a great degree of lateral motion, the glenoid cavity being broad and shallow; and whilst the pteregoid fossa, in which the muscles which *rotate* it are lodged, is of large size, the temporal fossa is comparatively small, no powerful *biting* motions being required by the nature of the food or the mode of obtaining it. The front teeth are fewer and smaller; but the surfaces of the grinding teeth are extended, and kept constantly rough by the alternation of bone and enamel. The extremities are more solidly formed, and have but little freedom of motion, the shoulder being scarcely more than a hinge-joint; the toes are consolidated and inserted into a hoof, which is double or single, according as the animal ruminates or not. The whole body is heavier in proportion, the nutritive system being more complicated; and the muscles which enable the tiger to lift considerable weights in his mouth, are here necessary to support the weight of the head itself.

209. A little consideration will show that the existence of this adaptation of parts is nothing more than a *result* of other laws of development. It is evident that if it were deficient, the race must speedily become extinct, the conditions of its existence being no longer fulfilled; these conditions being, for the whole organism, what the vital stimuli already described are for its individual properties. An animal with the carnivorous propensity of the tiger, for instance, and the teeth or hoofs of a horse, could not remain alive, from the want of power to obtain and prepare its aliment; nor would a horse be the better for the long canine teeth of the tiger, which would prevent the grinding motion of his jaws required for the trituration of the food. The statement above given cannot, therefore, be regarded as a *law*, since it is nothing more than the expression, in an altered form, of the fact that, as the life of an organised being consists in the performance of a series of actions which are dependent upon one another, and all directed to the same end, whatever seriously interferes with any of those actions must be incompatible with the maintenance of existence. The splendid discoveries of Cuvier and other anatomists, who have succeeded in determining from minute fragments of bones the characters of so many extraordinary species of remote epochs, have resulted only from the union of a sagacious application of this fact, with the

laborious comparison of these remains and the similar parts of animals at present existing. Until the laws of formation are discovered, which have operated in producing one result as well as the other, no briefer process than this can be adopted.

210. That these laws may be most advantageously pursued while disregarding for a time the particular connection of organs with the functions they appear designed to serve, will be hereafter shown (CHAP. XVII.); at present it may be remarked that those who have dwelt most upon this adaptation of the structure of living beings to the external conditions in which they exist, appear to have forgotten that these very conditions might be regarded, with just as much propriety, as specially adapted to the support of living beings. We have as much ground to believe that this earth, with all its varieties of season, temperature, light, moisture, &c., was adjusted for the maintenance of plants and animals upon its surface, as that these plants and animals were created in accordance with its pre-existing circumstances. The Natural Philosopher does not regard it as a sufficient explanation of the astronomical or meteorological changes which he witnesses, that they are for the benefit of the living inhabitants of the globe; and yet, as it has been already shown, they furnish conditions of vital action as important as those afforded by organised structure. The Philosophical Anatomist, therefore, does not regard the object or function of a particular structure as a sufficient account of its existence; but, in attaining the laws of its formation independently of any assumption of an end, he really exhibits the primary Design in a much higher character than in deducing it from any limited results of its operation.

CHAPTER IV.

GENERAL VIEW OF THE FUNCTIONS OF ANIMATED BEINGS, AND THEIR MUTUAL RELATIONS.

211. It has been stated (§ 4—6) to be the object of the Physiologist, to ascertain the laws regulating the changes which constitute the Life of organised beings; and that in order to arrive at any certain general conclusions respecting them, he must collect and compare all the facts of similar character, with which the study of the animated creation furnishes him. The changes which occur during the Life of any one being, are of themselves inadequate to furnish the required information; since this presents us only with a group of dissimilar phenomena, incapable of comparison with each other, or permitting it but to a low degree. Were

we to derive all our notions of Physiology from the history of one of the simple cellular plants, we should obtain but very vague ideas as to the character of its different nutritive processes; since we cannot separate these from one another, and investigate them apart. And, on the other hand, we should be apt to form very erroneous conceptions of the essential conditions of these processes, were we to study them only in their most complex form and specialised condition, and reason thence as to their dependence upon particular kinds of structure. It is only, then, from a comprehensive survey of the whole organised creation,—embracing the unobtrusive manifestations of life which Nature displays at one extremity of the scale (as if to show the simplicity of her operations), as well as those evident actions which every moment displays to us in her most elaborate works,—that any laws possessing a claim to general application can be deduced.

212. A careful examination, however, of the vital operations of the human system, or of any other of similar complexity, will reveal much more regarding the essential conditions of life, than a superficial glance could ascertain from them. Thus, if the series of phenomena be enquired into, which constitute the Function of Respiration, it will be found that, whilst some of these are indispensable to the continuance of life, and can only be performed under the conditions supplied by the organised system, other actions are merely superadded for the purpose of facilitating them; and these, if from any cause not performed by the mechanism contrived for their production, may be artificially imitated, with a degree of success exactly proportional to the perfection of the imitation. The essential part of the function of Respiration is the aeration of the blood; that is to say, an interchange of ingredients between the fluid and the air, resulting from its exposure, either directly to the atmosphere, or the gases diffused through water. All the changes which are associated as partaking in the function, share in it only by contributing to this, the real constituent of it. The alterations in the capacity of the chest, which are effected by the actions of the diaphragm and of the external muscles, have only for their object the renewal of the quantity of air in contact with the membrane through which the blood is exposed to it. These actions are really a part of the functions of the Muscular and Nervous systems; and are only associated under that of Respiration, on account of their obvious tendency towards its essential purpose. They have no share in the production of the aeration of the blood, except by supplying its conditions; and if these conditions can be supplied independently of them, the essential part of the function will be performed as when they were concerned in it.*

* Thus, in Asphyxia (§ 152 *note*) the deficient supply of arterialised blood to the brain soon paralyses its functions; and the nervous stimulus required for the respiratory movements being withheld, those movements cease. But, if the chest be artificially inflated, and emptied again by pressure, and these alternate movements be sufficiently prolonged to re-excite the circula-

213. By an analysis of this kind applied to the other functions, similar conclusions might be arrived at respecting their essential character; for it will appear in every one of them, that some of the changes which are thus grouped together are *essential*, and others *superadded*. But these conclusions do not possess the same certainty as if they were founded upon a broader basis; nor are they so easily attained. For, to revert to the instance just quoted, *observation* alone of the vital phenomena of the lower animals, will reveal what could only be determined in man by *experiment*. Until an experiment (the insufflation of the chest) had been found successful in continuing the aeration of the blood, it could not be certainly known that the respiratory movements had not some further share in the function than that of mechanically renewing the air in apposition with the circulating fluid. But when the conditions of the function are examined in the lower animals, it is found that these are varied (the essential part being every where the same) to suit the respective circumstances of their existence. Thus, Reptiles, having no diaphragm, are obliged to fill the lungs with air by a process which resembles swallowing. In Fishes and other aquatic animals, to have introduced the required amount of the dense element they inhabit into the interior of the system, would have occasioned an immense expenditure of muscular power; and the required purpose is answered by sending the blood to meet the water, which is in apposition with the external surface. And in those simple gelatinous creatures, in which the fluids appear equally diffused through the whole system, their required aeration is effected by the simple contact of the water with the general surface: the stratum in immediate apposition with it being renewed, either by their own change of place; or, if they are fixed to a particular spot, through the means they possess of creating currents, by which their supply of food is brought to them. And, going still further, we find in Plants, the essential part of the function of Respiration performed without any movement whatever; the wide extension of the surface in contact with the atmosphere affording all the requisite facility for the aeration of the circulating fluid.

214. A brief but comprehensive view of the vital phenomena common to all living beings, as well as of those peculiar to the Animal kingdom, exhibiting their mutual dependence, and distinguishing their essential conditions from those which are superadded or accidental, will assist in the due appreciation of the details hereafter to be given as to

tion of the blood through the lungs, by aerating that which had been stagnated there, the whole train of vital actions may be again set in motion. Or, if the cessation of the respiratory movements results from a cause primarily affecting the nervous system—as when narcotism is induced by poisoning with opium—and the blood be, in consequence, stagnated in the lungs by the want of aeration, this change, so essential to the continuance of vitality, may be prolonged by artificial respiration, until the narcotism subsides, unless the dose have been too powerful.

their individual character. In all living beings, the appropriation of alimentary matter from without,—its conversion into a nutritious fluid, of which the elements supply materials for the growth and renovation of the fabric, and thus maintain its vital properties,—and the excretion of the particles unfit for these purposes,—constitute the sum of the vital acts by which the existence of the individual is *immediately* supported. If due allowance be made for the differences occasioned by the possession of the faculties of sensation and voluntary motion, it will be found, on close examination, that there is a fundamental correspondence in the mode in which these processes are performed in all the members both of the Animal and Vegetable kingdoms; their *apparent* differences resulting from the necessary adaptation of their organs to the respective conditions of existence. These functions are, therefore peculiarly *vital;* and are spoken of as constituting the *organic* or *vegetative* life of the being.

215. But the maintenance of *individual* life is not all that is required from the powers of an animated body. It has been stated (§ 146) to be a general law of organisation, that all organised structures must be produced by others previously existing; no living being ever taking its origin from spontaneous combinations of inorganic matter.* Since, then, the limited duration of each individual existence would soon occasion the extinction of the race, if no provision were made for perpetuating it, the necessity for a succession of new creations can only be obviated by the endowment of each organism with the means of preparing a germ, which, when sufficiently mature, may support an independent existence, execute all the vital changes which are characteristic of the form which it has assumed, and in its turn originate new beings by a similar process. This function, which is common to all living beings, is termed that of Reproduction.

216. Now, it may be observed, before proceeding further, that there is a certain degree of antagonism between the nutritive and reproductive functions, the one being executed at the expense of the other. The reproductive apparatus derives the materials of its operations through the nutritive system, and is entirely dependent upon it for the continuance of its function. If, therefore, it be in a state of excessive activity, it will necessarily draw off from the individual fabric some portion of the

* In cases which have been thought to support the contrary doctrine, such as the appearance of parasitic Fungi (§ 64, 66) on decaying organised substances, the production of animalcules in decomposing infusions (§ 113), or the existence of Entozoa in the animal tissues (§ 111), a different explanation may fairly be offered; as it is impossible to prove in any of these cases that germs were not in reality present. The admission that the beings which appear with such remarkable uniformity in these situations, have really an origin from pre-existing organisms, becomes much easier if it be admitted on the other side (as it seems reasonable to do), that the form of the being which is there produced need not always correspond with that which afforded the germ. This subject will hereafter be more fully enquired into (CHAP. XIII.).

aliment destined for its maintenance. It may be universally observed that where the nutritive functions are particularly active in supporting the *individual*, the reproductive system is in a corresponding degree undeveloped,—and *vice versâ*. Thus, it has been stated that in the Algæ, the dimensions attained by single plants exceed those exhibited by any other organised being; and in this class the fructifying system is often obscure, and sometimes even undiscoverable. In the Fungi, on the other hand, the whole plant seems made up of reproductive organs; and as soon as these have brought their germs to maturity, it ceases to exist. In the flowering plant, moreover, it is well known that an over-supply of nutriment will cause an evolution of leaves at the expense of the flowers, so that what actually would have been flower-buds, are converted into leaf-buds;—or the parts of the flower essentially concerned in reproduction, namely, the stamens and pistil, are converted into foliaceous expansions, as in the production of double flowers from single ones by cultivation;—or the fertile florets of the disk in composite species, such as the Dahlia, are converted into the barren but expanded florets of the ray. And the gardener who wishes to render a tree more productive of fruit, is obliged to restrain its luxuriance by pruning, or to limit its supply of food by trenching round the roots.

217. The same antagonism may be witnessed in the Animal Kingdom; but as a third element (the sensory and locomotive apparatus) here comes into operation, it is not always so apparent. It appears to be a universal principle, however, that during the period of rapid growth, when all the energies of the system are concentrated upon the perfection of its individual structure, the reproductive system remains dormant, and is not aroused until the comparative inactivity of the nutritive functions allows it to be exercised without injury to them. Thus, in the larva condition of the insect, the assimilation of food and the increase of its bulk seem the sole objects of its existence (§ 87); its locomotive powers are only adapted to obtain nourishment that is within easy reach, to which it is directed by the position of its egg, and by an unerring instinct that seems to have no other end. The same is the case, more or less, with all young animals; although there are few in which voracity is so predominant a characteristic. In the Imago, or perfect insect, on the other hand, the fulfilment of the purposes of its reproductive system appears to be the chief and often the only end of its being. The increased locomotive powers which are conferred upon it, are evidently designed to enable it to seek its mate; its instinct appears to direct it to this object, as before to the acquisition of food; it now shuns the aliment it previously devoured with avidity, and frequently dies as soon as the foundation is laid for a new generation, without having taken any nutriment from the period of its first metamorphosis. In the adult condition of the higher animals, again, it is always found that, as in plants, an excessive activity of the

nutritive functions indisposes the system to the performance of the reproductive; a moderately-fed population multiplying (ceteris paribus) more rapidly than one habituated to a plethoric condition.

218. There is no reason to believe that vegetables possess anything like the *consciousness* which we know to exist in ourselves, and which, from the analogy of its manifestations, we believe to exist in other animals. In man, this consciousness is but the foundation of a series of mental operations, in which many different classes of actions may be recognised. These may altogether be spoken of as resulting from his *psychical* endowments. Whether those endowments are to be regarded as *properties*, resulting from certain dispositions of matter, or whether matter affords only the mechanism by which they are brought into relation with the external world, is a question more of speculative interest than of practical importance. That in descending the animal scale, this mechanism becomes less and less complex, and the psychical powers themselves less numerous and varied, until they are at last reduced to little else than mere consciousness, is acknowledged by all. And it is thus seen that the Animal Kingdom has no more distinctive separation from the Vegetable, than its principal groups exhibit amongst each other. The psychical endowments of animals, in whatever degree possessed, require for their exercise the means of information as to the condition of the external world, which is afforded by the faculty of *sensation;* as well as the capability of altering their own relation to it, which is effected by the apparatus of *locomotion*. These functions then are peculiarly *animal* in their character, and they are spoken of as constituting *animal life*, in contradistinction to those of organic life.

219. When the animal functions are reduced to their lowest degree, it is often very difficult to obtain satisfactory evidence of their being exercised at all; since their manifestations scarcely differ from those organic changes which may occur without their participation. Thus, when the tentacula of the Hydra or other polypes are touched, they suddenly contract, and endeavour to enclose the substance which affects them; but from such actions alone, we should have no right to infer that either sensation or volition are possessed by this being, since the Sensitive plant and the Dionœa perform movements precisely analagous (CHAP. XV.). We observe, too, that the gemmules of the Sponges and Polypes swim about for some time previously to fixing themselves, apparently with a choice of direction, and a perception of obstacles; yet the sporules of many Algæ are almost equally active, and it would be difficult to point out any essential difference between the two instances. In many cases, too, the influence of external causes, such as movement of the fluid itself or the attraction of other bodies, renders it impossible to determine what are voluntary motions, and what are therefore to be regarded as possessing an exclusively animal character.

220. All physiologists agree that *structure* alone presents no certain diagnostic mark, by which the simplest and most approximated groups of the two kingdoms may be distinguished. In the higher classes of animals we may detect certain organs which we know by experience to minister to their peculiar functions; but these, becoming gradually simplified as we descend the scale, at last disappear altogether (at least to our means of observation), whilst some degree of the functions appears still to remain. Again, there are certain modifications which the apparatus of organic life is seen to undergo in the higher animals, for the purpose of adapting it to the conditions of their existence; and upon these some naturalists have relied as diagnostic peculiarities (§ 239). But these also are perceived to disappear, as the psychical endowments of the beings, and the organs by which they are brought into relation with the external world, occupy a less prominent situation. This has been already seen with regard to the symmetrical disposition of the parts of the fabric; and it will be hereafter shown in more detail, when the individual organs are described.

221. On the other hand, in proportion to the complexity and extent of the psychical endowments of each species of animals, may their influence over the conformation of the organic structure be perceived; so that it becomes more and more removed from that which is presented by vegetables, the chief end of whose existence appears to be the elaboration of such a structure from the elements furnished by the inorganic world. In man, the being that possesses the largest share of these capabilities, the whole apparatus of organic life would seem destined but to serve for the maintenance of the animal functions. The processes of nutrition are here chiefly directed towards perfecting the nervous and muscular systems, and bringing their functions into most advantageous operation; whilst in many of the lower animals this would seem quite a subordinate object, the extension of the organs of vegetative life being, as in plants, the direction taken by their development. Hence it may be stated generally, that the more exalted is the *animality* of any particular being (or, in other words, the more complete the manifestation of characters peculiar animal), the more closely are the organic functions brought into relation with it.*

222. Yet, however intimate may be the bond of union between the organic and animal functions, the former are never *immediately* dependent upon the latter; although, as it has been already shown (§ 31 and 212),

* A simple illustration will render this evident. In certain of the lower tribes of animals, whose locomotive powers are feeble and general habits inactive, the circulation of nutritive fluid is carried on nearly in the same manner as in plants; there is no central organ for propelling it through the vessels, and ensuring its regular and equable distribution; and its motion appears dependent upon the forces created in the individual parts themselves. In the higher classes, on the other hand, the comparative activity of all the functions, and the peculiar dependence of those of animal life upon a constant supply of this vital stimulus, require a much more elaborate apparatus, and especially a central power, by which the movements of the fluid in the individual parts may be harmonised, directed, and controlled.

they sometimes depend upon them for the conditions of their maintenance. There is no good reason to believe that "nervous agency" is essential to the processes of nutrition and secretion in animals, any more than to the corresponding processes in plants. This is a question which may be more certainly determined by *observation* than by any *experiment* which can be made. That they are very readily influenced by changes in the condition of the nervous system, is universally admitted; and it is the intimacy of this connection which has given rise to the idea of a relation of *dependence*, and which prevents that idea from being disproved. In order to cut off all nervous communication from any portion of the organism—a gland for example,—so violent an operation is required (involving no less than the complete division of the blood-vessels, on which a plexus of ganglionic nerves is minutely distributed), that it is impossible to say that the disturbance of the function may not be owing to the shock produced on the general system. Observation, however, shows us that these processes are performed in the most complex and elaborate manner by vegetables, in which all the attempts that have been made to prove the existence of a nervous system have signally failed, (these attempts seeming to have been only excited by an indisposition to admit the possibility of any vital actions being independent of "nervous influence");—that the lowest animals appear equally destitute of a nervous apparatus destined to influence them;—and that in the higher classes we find such an apparatus developed, just in proportion as the necessity arises, from the complication and specialisation of the organic functions, for their being harmonised and kept in sympathy with each other and with the conditions of the animal system, by some mode of communication more certain and direct than that afforded by the circulating apparatus, which is their only bond of union in plants.*

223. The *Absorption* of alimentary materials is the first in the train of Vital operations, and is common to Plants and Animals, although performed under somewhat different conditions in the two Kingdoms. The *plant* derives its support immediately from the surrounding elements; it is fixed in the spot where its germ was cast; and it neither possesses a will to move in search of food, or any locomotive organs for so doing. By the peculiar structure of its roots, however, it is endowed with some power of obtaining aliment not immediately within its reach (§ 249). The *animal* possesses a recipient cavity, in which its food, consisting of matter previously organised, undergoes a certain preparation or *digestion*, before it is taken up by the absorbents, which are distributed on its sides. The

* This, it may be safely affirmed, is all that has yet been *proved* of the functions of the sympathetic or ganglionic system of nerves; and any hypothesis which presumes further, must be regarded as unphilosophical, because unnecessary to explain facts. The *onus probandi* certainly rests with those who maintain what is contrary to the important analogy just adduced, and not with those who frame their opinions in harmony with it.

introduction of food into this cavity, or its *ingestion*, seems more and more dependent upon the animal functions, in proportion as we ascend the scale. The ciliary movements of the lower classes of animals, which produce currents of such rapidity in the water that surrounds them, and thus bring a supply of food to the entrance of the digestive cavity, are probably to be regarded as of the same involuntary character as those which exist in the higher (§ 110). In animals of more complex structure, the process of obtaining food requires a much greater variety of movements, which are evidently dependent on the muscular and nervous systems; but these may still be regarded as not involving changes of a strictly mental character. Rising still higher, however, we find the psychical endowments of the animal evidently concerned in procuring its support; and in man, where they exist in their greatest amount, the comparative imperfection of the bodily structure increases the reliance upon them (CHAP. V.).

224. The alimentary materials taken up by the absorbent system, are carried by the *Circulation* into all parts of the fabric. This movement, so evident in the highest classes of plants and animals, becomes less necessary in the lower, where the absorbent surface is in more immediate relation with the parts to be supplied with nourishment (§ 281). Besides affording this continued supply, the circulating system carries the vital fluid to the organs destined to separate from it the impurities it may have contracted in its course, to maintain the necessary balance between its different ingredients, and to effect other changes whose nature is little understood. This function, in animals as in plants, is entirely independent of the will, and, in its usual condition, is unaccompanied with consciousness. The muscular apparatus is concerned in it only to harmonise it with the conditions of animal existence (§ 31); and nervous agency merely brings it into sympathy with other operations of the corporeal and mental systems. (CHAP. VI.).

225. Besides conveying to the various tissues the materials required for their renovation, and serving as the stimulus necessary to the performance of their functions, the current of circulating fluid takes up, in animals especially, the particles which have discharged their duty in the structure, and which are either to be rendered again subservient to the process of nutrition, by admixture with alimentary matter newly absorbed, or to be separated from the general mass, and carried out of the system. This function is termed *Interstitial Absorption;* and it is performed, in the higher animals, by a special vascular apparatus (CHAP. VII.).

226. The alimentary materials first taken up by the absorbents must undergo various changes before they become part of the organised fabric. It is, in fact, in these changes that the Life of the being essentially consists; those already mentioned being merely subservient to them. There is much difficulty in tracing them with precision, either in the animal or

vegetable systems. The first which is perceptible, is the formation of *organisable products* by a new combination of the elements supplied by the food. This appears to commence, in vegetables, as soon as these elements are absorbed; and the same may probably be said with regard to animals, though the preparatory process of digestion seems to partake in it. The organisation of the combinations thus formed, appears to commence whilst they are still diffused through the circulating fluid; and vital properties are probably simultaneously communicated to them. The elaborated sap of plants, and the chyle and blood of animals, contain these organisable products in abundance, but not in a state of mere admixture; and the existence of regular globules in them resulting from incipient organisation, appears to be a characteristic of nutritious fluids. From these materials the individual tissues of the fabric are created and renewed, by the process of *Nutrition;* each deriving from the blood the portion which its composition requires. This process is influenced, through the nervous system, by conditions of the mind or of the general fabric; but it does not seem to *depend* upon that system for its maintenance (CHAP. VIII.).

227. In order to preserve the circulating fluid in the state required for the due performance of its important functions, means are provided for separating and carrying out of the system whatever may be superfluous or injurious in its constituent parts; as well as for elaborating from it certain fluids having a destined use in the economy. These changes may be comprehended in the general term *Secretion*, the former constituting the function of *Excretion*. This is one no less important to the health of the system than the absorption of aliment; and in proportion to the complexity of the structure, we find a multiplication of the excreting organs, as well as a variety in their products. The loss of fluid by *Exhalation*, and of superfluous carbon by *Respiration*,* are constant, however, in all living beings. The evolution of heat and light appear to result, where they occur, from a peculiar modification of this function; and that of electricity depends upon similar changes. These changes seem to have no more immediate dependence upon the nervous system than that of nutrition; and they will take place, to a certain extent, after the final extinction of the animal powers. They are, however, most intimately dependent upon the maintenance of the circulation, and soon come to an end if that ceases; but it is probable that, in particular cases, they are kept up by the *capillary* circulation, after the action of the heart is extinct (CHAP. IX.—XII.).

228. The essential difference between the function of *Reproduction* and that of *Nutrition* consists in this,—that in the latter case the alimentary materials are appropriated in renovating the structures of the

* Reasons will hereafter be given (§ 369) for regarding this function as a branch or subdivision of that of Excretion.

individual,—whilst in the former they are applied to the production of a new structure, which is for some time a part of the parent being, but which subsequently becomes a *new* individual. In the lowest classes of Plants and Animals we often find these two functions completely blended together (§ 513). In many of the inferior tribes of each kingdom, a single organ only is necessary for the production and maturation of the germ; and the process then goes on as regularly and uninterruptedly as any of the nutritive functions. Even where two distinct kinds of organs are necessary, it may proceed without any interference of will or excitement of consciousness on the part of the individual; for these may be united in the same being, as in hermaphrodite flowers; or, if separated, as in monœcious species, their functions may be made to concur by external influences.* There are some animals in which the two classes of organs are united in the same individual; and the actions necessary to bring them in relation are probably of a purely instinctive character, like those which are designed to bring food to the digestive organs. But in the higher classes, where the organs exist in separate individuals, the will, excited by a powerfully-stimulating propensity, is evidently the instrument by which they are brought into relation with one another; and in man, where this propensity is connected with a nobler and purer passion, not only the will, but the highest powers of the intellect are put in action to gratify it. But even here, the *essential* part of the function is as completely independent of mental influence as in the plant or simplest animal (CHAP. XIII., XIV.).

229. The function of *Muscular Contraction*, to which nearly all the sensible motions of the higher animals are due, is one which has an important connection with almost every one of the vital operations; although, as already explained, this connection is mostly of an indirect character. The property of contractility on the application of a stimulus, is not, however, confined to animals; since it is possessed by many of the vegetable tissues, and has an important relation with their nutritive processes. In the lowest animals, also, it seems generally diffused through the system; and appears to be, in like manner, generally excited by external stimuli. But in the higher classes, it is concentrated in a special texture, and is called into operation by a new stimulus, the nervous power, which originates in the individual itself. By this means it is brought under subordination to the will, and is made the instrument of changing the relations between the bodily system and the external world (CHAP. XV.).

230. The functions of the *nervous system* are twofold. First, to bring the conscious mind, (using that term in its most extended sense, to denote the psychical endowments of animals in general,) into relation

* Thus, the pollen of one flower is often conveyed to the stigma of another at some distance, by the agency of the wind, insects, &c.

with the external world; by informing it, through the medium of the organs of sensation, of the changes which material objects undergo; and by enabling it to act, by other appropriate organs, upon various beings, animate and inanimate. And also, to connect and harmonise different actions in the same individual, without necessarily exciting any mental operation. But, in the words of a profound writer on this subject, "mental acts, and bodily changes connected with them, are not merely *superadded* to the organic life of animals, but are intimately connected or interwoven with it; forming in the adult state of all but the very lowest animals, part of the conditions necessary to the maintenance of the quantity, and of the vital qualities, of the nourishing fluid on which all the organic life is dependent."* "The nervous system," it is elsewhere remarked by the same author, "lives and grows within an animal, as a parasitic plant does in a vegetable; with its life and growth, certain sensations and mental acts, varying in the different classes of animals, are connected by nature in a manner altogether inscrutable to man; but the objects of the existence of animals require that these mental acts should exert a powerful controlling influence over all the textures and organs composing an animal." It will hereafter be shown that this influence is exerted just in proportion to the development of the nervous system; and that, whilst in the lowest animals the functions of organic life are performed nearly under the same conditions as in plants, they are, in the highest classes, dependent for their maintenance upon its operations (CHAP. XVI.).

The remainder of this volume will be devoted to the examination of these functions in detail, constituting the department of SPECIAL PHYSIOLOGY.

* Alison's Physiology. Supplement, p. 3.

BOOK II.

SPECIAL AND COMPARATIVE PHYSIOLOGY.

CHAPTER V.

INGESTION AND ABSORPTION OF ALIMENT.

General Considerations.

231. It has been stated that the peculiar characteristic of living beings in general, is the power which each possesses of maintaining, for a certain period, its regular external form and internal structure, in defiance of the common physical properties of its component parts; whilst, at the same time, all these parts are undergoing, in greater or less degree, alterations both in composition and conformation. If we consider the development of any one germ, from the time of its first quitting the parental system to its final decay, we observe that it is not so much the *structure itself* which is furnished by the parent (as from a superficial view of the reproductive function in the higher animals we might be led to suppose), as the *capability* of forming that structure, by the conversion of the materials supplied by the external world into organised tissues endowed with peculiar and diversified properties,—which process is termed *assimilation.* These materials, then, constitute the *aliment* necessary for the first development of the living system; and in proportion to the activity of its operations will be the occasion for their supply. Thus, the larvæ of the flesh-fly produced from the eggs laid in carrion are said to increase in weight 200 times in the course of twenty-four hours; and their voracity is consequently so great, that it was maintained by Linnæus that three individuals and their immediate progeny (each female giving birth to at least 20,000 young, and a few days sufficing for the production of a third generation,) would devour the carcase of a horse with greater celerity than a lion (see also § 87). A still more extraordinary instance of rapid growth

is found in the vegetable Kingdom. The *Bovista giganteum*, a large Fungus of the puff-ball tribe, has been known to increase in one night from the size of a mere point to that of a huge gourd, estimated to contain 47,000,000,000 cellules.

232. But the supply of aliment is not required only for the original development of the organism, but for the continued maintenance of the perfect structure and properties of its various parts. The tendency to decomposition exists not only in dead animal or vegetable matter, but in the living tissues; and, as it has been already stated (§ 18), it does not seem improbable that the peculiar influence of Vitality is not so much exercised in resisting that tendency (as some have supposed), as in providing for its effects by the removal or *deportation* of all particles in a state of incipient decay. It seems at any rate certain, that the process of interstitial absorption, by which these particles are carried off, is performed in each tissue with an activity proportioned to its tendency to spontaneous decomposition; and it is very evident that the supply of new alimentary materials must be at least equal in quantity and regularity. This may, therefore, be regarded as the principal source of the continued demand for nutriment in the adult system.

233. Since living beings have not only to maintain their existence in the midst of favourable external conditions, but are liable to the occasional infliction of disease and to damages resulting from mechanical violence, they would be irrecoverably injured by such attacks, were it not that, in the nutritive system, the means are provided for repairing their effects. The regeneration of various organs and tissues, after what appeared their total destruction, is a process no less remarkable than their first formation, and no less evidently displays the foresight of the original Designer. In many of the harder parts both of animals and vegetables, which exhibit so little tendency to spontaneous decay as to be capable of preservation after death to an almost indefinite period, the absorption of old particles and the deposition of new take place so slowly in the natural condition as to be scarcely perceptible; but when disease or injury calls the actions of reparation into play, they are effected with a rapidity and certainty not surpassed in any other parts of the system. The other demands upon the nutritive functions which arise out of the conditions of the organised structure are principally connected with its physical relations. Thus, where the external tegument is dense, and does not possess within itself the power of adaptation to the altered form of the body, it must be thrown off and replaced by a new one, as we see in the Crustacea (§ 84). Again, the constant movements of the body necessarily produce a waste or wearing away of the materials both of its harder and softer structures, just as in any piece of mechanism; hence arises one cause of the increased demand for nutriment which is produced by continued muscular exertion. This general statement will

suffice to show the connection between the activity of the different vital processes, and the dependence of the being upon the supply of new materials for its structures; since upon the perfection of these structures it relies for the performance of all its vital actions.

234. Amongst the general differences between the Animal and Vegetable Kingdoms, none are more striking than those existing between the aliments on which they are respectively supported, and the mode of their *ingestion* or introduction into the system. The essential nutriment of plants appears to be supplied by the inorganic world, and to consist of water, with certain saline impregnations, and carbon. The water is derived partly from the fluid which percolates the soil, and partly from the moisture of the atmosphere. The carbon is principally obtained from the carbonic acid of the air; but most plants require for their healthy growth that it shall be introduced by the roots also. In all soils of moderate richness there exists a large quantity of the remains of organised structures, the upper layer of which is constantly undergoing some degree of decomposition by contact with the atmosphere, and carbonic acid is formed in it. The water which traverses such a soil, therefore, will become charged with this gas, just as when it flows from a spring in which a similar disengagement has taken place from other causes; and this state of solution appears to be that in which carbon may be most advantageously introduced into the vegetable system. It does not seem probable that the organic matter which rich soils contain is itself applied to the nutrition of the plant without this previous decomposition; for it is found that those which afford the most steady and equable supply of carbonic acid are the most favourable to vegetable growth; and that whilst it is sometimes necessary to retard the decomposition of animal manures (which may disengage carbonic acid so rapidly as to gorge the plants) by the addition of charcoal, it is advantageous to excite fermentation in others by the addition of yeast.

235. The opinion that carbon and water constitute the essential food of plants is confirmed by the fact that many, even of the more highly organised species, will grow in circumstances where no other kind of nutriment is accessible to them; and no one is ignorant that the simpler forms of Lichens will appear on barren rocks in the midst of the ocean, increasing by absorption from the atmosphere alone, and preparing by their decomposition a nidus for the reception of the germs of higher orders of vegetation. The only class of plants which seems to be dependent for its support upon matter already organised, is that of Fungi,—a group of peculiar interest, whether we regard the rapidity and luxuriance of their growth, the varied forms they assume, the importance of the offices they perform, or the universality of their diffusion, either as actively vegetating plants, or as dormant germs ready to be developed upon every opportunity. Like insects, they have been denominated the "scavengers

of nature," from their utility in removing the noxious products of decomposition; and they present us with two curious analogies with the animal kingdom, both resulting, no doubt, from the nature of their aliment. The large quantity of carbonic acid with which their absorbent system furnishes them, prevents the necessity of their deriving any additional supply of it from the atmosphere; but on the contrary, like animals, they have only to get rid of what is superfluous. The proportion of nitrogen contained in their tissues is much greater than in any other vegetable; so that *fungin*, a proximate principle which may be obtained from them, is as highly azotized as animal flesh. In the subsequent details relative to the structure and functions of the nutritive system of plants, the mode in which carbon is assimilated from the atmosphere will be described under the head of Respiration (although not properly a part of that function), since the conditions of vegetable growth require that the portion of the structure exposed to the air should perform this office, as well as that more strictly appertaining to it,—the aeration of the circulating fluid. Some curious superadded organs occasionally met with, which seem to shadow forth the stomach and digestive system generally regarded as peculiar to animals, will be presently described (§ 239).

236. Vegetables, then, seem to constitute the intermediate link in the scale of creation, between the inorganic world and the animal kingdom; and although in a few instances they are partially dependent upon the latter for their existence, it cannot be doubted that the general balance is greatly in favour of the supplies they afford. To furnish these supplies would indeed appear to be the great purpose of their being: for, as Dr. Roget has well observed, "the only final cause which we can assign for the series of phenomena constituting the nutritive functions of vegetables, is the formation of certain organic products calculated to afford sustenance to a higher order of beings. The animal kingdom is altogether dependent for its support, and even existence, upon the vegetable world. The materials of animal nutrition must, in all cases, have previously been combined in a peculiar mode, which the powers of organisation alone can effect."

237. It is a general law of vitality that the materials of nutrition can only be introduced into the living system in the fluid state; and although the ingestion of solid aliment by the higher animals might seem to contradict such a principle, a little examination into the character of their nutritive organs will show that they are framed in conformity with it. In addition to the absorbent system with which plants are furnished, and which is the medium of communication between the organic life and the external world, nearly all animals are provided with cavities for the reception of their food, and for its reduction to a state fit to enter the vessels. The necessity for these cavities arises out of the nature of the aliment

required by animals, which usually pre-exists in a form more or less solid; and also from the intervals which occur between the periods at which it is obtained. Whilst the roots of vegetables are fixed in the soil, and ramify through it in pursuit of their nutriment, animals, whose locomotive powers are necessary for the search after the food they require, may be said to carry their soil about with them; for their absorbents are distributed on the walls of the digestive cavity, just as those of plants are externally prolonged into the earth. This cavity is in all instances formed by a *reflexion* of the external surface, of which the *hydra* (§ 115) may be regarded as presenting us with the simplest example. It is merely a bag with one opening, which may be regarded as *all stomach*. A higher form is that in which the cavity has two orifices, and thus becomes a canal, such as is found in many of the infusorial animalcules; and all the complicated intestinal apparatus of the higher animals may be considered as a more extended development of this simple type. The food which is introduced into it is acted upon mechanically by the motion of the walls, and chemically by the secretions poured from the surface; so that the nutritious parts of it are separated from that which may be rejected, and are reduced to a fluid form.

238. That the process of digestion is really of no higher character than this, and that it has nothing to do with *organising* or *vitalising* the materials submitted to it, appears from *a priori* considerations, and from experiment also. The substances contained in the intestinal canal are usually as much exterior to the system, as if they were placed in contact with the skin; for we cannot regard them as introduced into it until they have been absorbed; and, up to this period, they hold precisely the same relation to the lacteal vessels, as the fluid which has percolated the soil bears to the roots of the plants which ramify through it. The experiments which have recently been performed on artificial digestion have precisely the same bearing (§ 258, 261).

239. Although the possession of a digestive cavity has been regarded by some physiologists as a prominent characteristic of animals, so that it has been gravely proposed to define an animal as "*un estomac servi par des organes*," it is by no means a universal endowment; for although there is no doubt that many of the minuter beings, which were formerly supposed to be destitute of such an organ, are really possessed of it in no very simple form, there is no less doubt that many others, during a part of their existence at least, are nourished by absorption from the exterior surface alone (§ 280). The difficulty of establishing a well-defined limit between the animal and vegetable kingdoms, upon a distinction of this kind, is increased by the fact that among plants we find many adapta-

tions of structure for the reception and preservation of aliment; some of which it would not be easy to exclude from any definition we might frame of a stomach. Concavities in different parts of the surface, fitted for the collection of the moisture caught from rain or condensed from dew, may frequently be observed; and these vary in the completeness of their structure, from the simple hollow formed in the leaf of the *Tillandsia* (wild pine of the tropics), or of the *Dipsacus* (teasel), to the extraordinary *ascidia* of the pitcher-plants. The exact method in which the fluid thus obtained is applied to the nutrition of the plant is not always evident. Sometimes the channelled leaves seem to convey it to the roots, by which it is absorbed in the usual manner. The function of the pitcher of the *Nepenthes* (Chinese pitcher-plant) has not been certainly determined; as it is difficult to ascertain how much of the fluid which it contains is collected from the atmosphere by the downy hairs that line its interior, and how much is secreted by the plant itself. The object of the pitchers of the *Dischidia* (Fig. 102) is, however, less doubtful, and their structure far more complicated. This curious plant grows by a long creeping stalk, which is bare of leaves until near its summit; and as, in a dry tropical atmosphere, the buds at the top would have great difficulty in obtaining moisture through the stem, a sufficient supply is provided by the pitchers, which store up the fluid collected from the occasional rains. "The cavity of the bag," says Dr. Wallich,* "is narrow, and always contains a dense tuft of radicles, which are produced from the nearest part of the branch, or even from the stalk on which the bag is suspended, and which enter through the inlet by one or two common bundles. The bags generally contain a great quantity of small and harmless black ants, most of which find a watery grave in the turbid fluid which frequently half fills the cavity, and which seems to be entirely derived from without." The earth has been justly spoken of as the common stomach of vegetables, supplying them with nutriment ready to be taken up by their absorbent system; in this curious plant the failure of its regular means of support has called forth the addition of an organ, which, like the stomach of animals, serves as a receptacle for the supplies it may occasionally obtain. According to Mr. Burnett,† in the pitcher of the *Sarracenia* a process still more like that of animal digestion goes on; for it appears that the fluid it contains is very attractive to insects, which, having reached its surface, are prevented from returning by the direction of the long bristles that line the cavity. The bodies of those which are drowned seem, in decaying, to afford a supply of nutriment as favourable to the growth of the plant, as a similar process on the leaves of the well-known *Dionæa muscipula* (Venus' fly trap),—to the health of which, a supply of animal food appears to be essential.

240. Although such instances as these may seem to contradict the

* Plantæ Asiaticæ rariores, vol. ii. p. 35. † Brande's Journal, vol. vi.

general statement, that plants derive the materials of their nutrition from the inorganic world, yet they probably do so more in appearance than in reality. In all cases where previously organised matter influences their growth, it is only whilst in a decomposing state, during which it is separated into its ultimate elements or very simple combinations of them (§ 234). In animal digestion, on the contrary, the proximate principles contained in the food appear to be immediately subservient to the formation of others of a higher order; and whatever tendency to disunion its elements might have previously manifested, this is immediately checked by the antiseptic qualities of the gastric fluid. We find in the animal kingdom, also, many apparent exceptions to the general statement which has been made respecting the source of their nutrition; for it often appears as if they derived their support in part, at least, from the inorganic world. Thus, the *Spatangus* (§ 106) fills its stomach with sand, but really drives its nutriment from the minute animals contained in it. The earth-worm and some kinds of beetles are known to swallow earth, but only to obtain from it the remains of organised matter which are mixed with it. In fact, the inorganic matter thus taken into the stomachs of these animals no more contributes to their nutrition, than the gravel swallowed by graminivorous birds, or the chalk eaten by a hen preparing to lay.*

241. The particular articles, which constitute the food of the different races of animals are as various as the races themselves. Some tribes in almost every division of this kingdom are maintained solely by vegetable food; and wherever plants exist, we find animals adapted to make use of the nutritious products which they furnish, and to restrain their luxuriance within due limits. Thus, the Dugong browses upon the submarine herbage of the tropics; whilst the Hippopotamus roots up with his tusk the plants growing in the beds of the African rivers; the Giraffe is enabled by his enormous height to feed upon the tender shoots which are above the reach of ordinary quadrupeds; the Rein-deer subsists during a large part of the year upon a lichen buried beneath the snow; and the Chamois finds a sufficient supply in the scanty vegetation of Alpine heights. Many species of animals, especially among the Insect tribes, are restricted to particular plants; and, if these fail, the race may for a time disappear. But there is probably not a species of plants which does not furnish nutriment for one or more tribes of insects, either in their larva state or perfect condition, by which it is prevented from multiplying to the exclusion of

* Among the human race some savage nations are in the habit of introducing large quantities of earthy matter with their food; and this sometimes through ignorant prejudice, but more frequently to give bulkiness to the aliment, so that the stomach may be distended,—as among the Kamschatdales who mix saw-dust or earth with their train oil. This example has been followed in civilized countries in times of scarcity; thus in the year 1832 a famine in Degernä, on the borders of Lapland, occasioned the flour and bark of trees, of which the bread was made, to be mixed up with siliceous earth.

others. Thus, on the oak not less than 200 kinds of caterpillars have been estimated to feed; and the nettle, which scarcely any beast will touch, supports fifty different species of insects, but for which check it would soon annihilate all the plants in its neighbourhood. The habits and economy of the different races existing on the same plant are as various as their structure. Some feed only upon the outside of the leaves; some upon the internal tissue; others upon the flower or on the fruit; a few will eat nothing but the bark; while many derive their nourishment only from the woody substance of the trunk. It is very curious to observe that many plants injurious to man afford wholesome nutriment to other animals; thus, Henbane, Nightshade, Water Hemlock, and other species of a highly poisonous character, are eaten greedily by different races of quadrupeds. Some cattle, again, will reject particular plants upon which others feed with impunity.

242. Every class of the animal kingdom has its carnivorous tribes also, adapted to restrain the too rapid increase of the vegetable-feeders, by which a scarcity of their food would soon be created,—or to remove from the earth the decomposing bodies which might otherwise be a source of disease or annoyance. The necessity of this limitation becomes evident if we consider the rapid multiplication which the prolific tendency of the herbivorous races would speedily create, until checked by the famine that would necessarily result from their inordinate increase. Thus, the myriads of insects which find their subsistence in our forest trees, if allowed to increase without restraint, would soon destroy the life that supports them, and must then all perish together; but another tribe (that of the insectivorous birds, as the Woodpecker,) is adapted to derive its subsistence from them, and thus to keep within salutary bounds the number of these voracious little beings. A very curious instance of the nature of the checks and counter-checks, by which the "balance of power" is maintained amongst the different races, is mentioned by Wilcke, a Swedish naturalist. A particular species of Moth, the *Phalæna strobilella* has the fir cone assigned to it for the deposition of its eggs; the young caterpillars, coming out of the shell, consume the cone and superfluous seed; but, lest the destruction should be too great, the *Ichneumon strobilella* lays its eggs in the caterpillar, inserting its long tail in the openings of the cone until it touches the included insect, for its body is too large to enter. Thus it fixes its minute egg upon the caterpillar, which when hatched destroys it.*

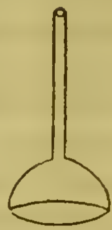
243. It has been said that all alimentary matter, in order to be introduced into the living system, must be presented to it in a fluid form;

* The Chapter on the "Economy of Nutritive Matter" in Dr. Roget's Bridgwater Treatise, and those of Mr. Lyell's Principles of Geology, on the "Equilibrium of Species," may be referred to for a more extended view of this very interesting subject than the limits of the present work will permit.

and that the reduction of it to that form is one object of the digestive processes of animals. The changes involved in its passage through the external integument, or that modification of it specially adapted for the purpose, constitute the function of *Absorption*. Before considering the particular conditions under which it is performed in the different classes of organised beings, it will be right to enquire what is its essential character, and how far physical laws may be applied to its elucidation. It was formerly the general opinion that Absorption is always effected by vessels, the open mouths of which, being in contact with the fluid, might imbibe it by capillary attraction, suction, or some other means. But anatomical enquiry has shown that in no one instance are absorbent vessels thus brought into immediate relation with the fluid to be received by them; but that the transmission always takes place through some tissue of a membranous character. Thus, we shall find that the skin of the higher animals, and the cuticle covering the general surface in plants, participate more or less in the function of Absorption, even where a special system is adapted to its performance; that in the inferior tribes, the external integument (with the reflexion of it which lines the digestive cavity in animals) is its sole medium; and that neither in the roots of plants, nor in the walls of the intestinal canal in animals, do the vessels terminate in open mouths, all the fluid which enters them having to traverse the tissue by which they are closed. The notion that *mere* capillary attraction has anything to do with the absorption of fluid into living systems is therefore completely untenable; but there is a remarkable phenomenon to which the term of *Endosmose* has been given by its discoverer Dutrochet, which, occurring under conditions supplied by inorganic materials alone, bears so strong a resemblance to this vital function that it is scarcely possible to disbelieve its partial concern in it. The following is a general statement of the phenomena in question.

244. If into a tube, closed at one end with a piece of bladder or other membrane, be put a solution of gum or sugar, and the closed end be immersed in water, a passage of fluid will take place from the exterior to the interior of the tube through the membranous septum; so that the quantity of the contained solution will be greatly increased, its strength being proportionably diminished. At the same time, there will be a counter-current in the opposite direction; a portion of the gummy or saccharine solution passing through the membrane to mingle with the exterior fluid, but in much less quantity. The first current is termed *endosmose*, and the counter-current *exosmose*. The increase on either side will of course be due to the relative velocity of the currents; and the changes will continue until the densities of the two fluids are so nearly alike as to be incapable of maintaining it. The greater the original difference (provided that the denser fluid be not actually viscid, but be capable of mixing with the other), the more rapidly and powerfully will

the process be performed. The best means of experimenting upon these phenomena is afforded by a tube narrow above, but widely dilated below, so as to afford a large surface to the membrane, compared with that of the superincumbent column, which will then increase in height with great rapidity. By bending this tube into the form of a syphon, and introducing into its curve a quantity of mercury, the force as well as the rapidity of the endosmose between different fluids may be estimated with precision. Although it is not universally true that the activity of the process depends upon the difference in density of the two fluids (for in one or two cases the stronger current passes from the denser to the lighter), it seems to be so with regard to particular solutions, as those of gummy or saccharine matter. No endosmose takes place between fluids which will not mingle, such as oil and water; and very little between such as act chemically on each other. Although an organic membrane forms the best septum, yet it has been found that thin laminæ of baked pipe clay will suffice for the evident production of the phenomenon; and that porous limestones possess the same property in an inferior degree. It is evident, then, that however obscure may be the nature of the process, and however difficult it may be to explain it on physical laws, these alone are concerned in it.*



245. It may reasonably be enquired how far the passage of fluid through membranes or tissues in the living body may be explained on this principle. It has been maintained that this is a purely vital change, because it does not occur except during the continuance of life. But it may be alleged, on the other side, that if we regard the other vital actions as furnishing the *conditions* of endosmose, the absorption of fluid may itself be considered as only an instance of the phenomenon. That this is the case in the Vegetable kingdom, subsequent details will show, and there will be no difficulty, therefore, in understanding why the process should cease with life: the function of Absorption in Animals cannot, however, be so conveniently studied, and its true character has not yet been satisfactorily elucidated. Still there seems much reason to believe that it is here, also, due to physical laws acting under conditions supplied by the living system; for transudation readily takes place through dead as well as living animal membranes, even where these, instead of forming a distinct septum, as in the production of Endosmose, are in contact with the tissues on the other side. Thus, Lebküchner found that oil of turpentine and camphor placed on the skin of a rabbit, 12 hours after death, communicated, in the space of 10 hours, their peculiar odours to a paper placed on the internal surface of that membrane. A solution of prussiate

* For further information on this curious subject, see the Article Endosmosis in the Cyclopædia of Anatomy and Physiology, and Dutrochet's Memoires, Anatomiques et Physiologiques, tom. i.

of potass penetrated in 5 hours; sulphuric acid in 6 hours; and acetic acid in 24 hours. Ink, and a solution of muriate of soda, had not passed in 24 hours; and a solution of ammoniuret of copper required two days for its transit.* These experiments go far to confirm the view, which will be hereafter stated (§ 250), that what has been termed the *selecting power* of absorbent surfaces, by which they take up some fluids (saline solutions for instance) and reject others, is not due so much to their peculiar vital properties, as to the physical relations between their tissues and the substances brought into contact with them. Again, Magendie immersed the amputated paw of a rabbit in ink, and the cellular membrane became coloured. He formed a bag from a piece of human skin, the epidermis being internal, and then filled it with water;—transudation took place rapidly: but when the experiment was reversed, and the epidermis placed externally, it became raised into a blister; thus showing that, from some physical causes, the passage of fluids takes place through it much more readily in the internal than in the external direction.† It is very easy to explain on this theory why absorption should take place so much more rapidly and energetically during life than after death; since the quantity of fluid which first penetrates the membrane is conveyed no further into the system, unless there is a demand for it; and it therefore saturates the tissues with which it is in contact, and prevents the admission of more. But when the fluid so absorbed is constantly being drawn off for the purposes of the economy, a continual demand for a renewed supply is created, and thus the action becomes one of the most regular of those subservient to Life.

Absorption in Vegetables.

246. In the lowest orders of Plants we find this function performed under its most simple conditions. The division of *Aphyllous* (leafless) CRYPTOGAMIA, including the Algæ, Lichens, and Fungi, presents a remarkable similarity of internal structure, concealed under great diversity of external form. The substance of all is composed of vesicles more or less firmly united to each other, and but slightly altered from their original spheroidal form; and the envelope which surrounds them can seldom be regarded as a distinct structure, as it generally differs but little from the remainder of the cellular tissue. The simplest forms of ALGÆ, such as the *Protococcus nivalis* (Fig. 59), consist of individual cellules, each of which seems to be in itself capable of nutrition and reproduction; but in the higher genera, the plant is composed of a mass of such cellules united together, sometimes in single rows, as in the *Confervæ* (Fig. 61), sometimes in a more definite and expanded form, as in the Sea-weeds in

* Madden on Cutaneous Absorption, p. 33.

† The first Volume of the "Leçons sur les Phénomènes Physiques de la Vie," contains a great mass of evidence of the same character.

general. In all of these, however, the whole surface appears to be endowed with the power of absorption to nearly an equal degree; and although the semblance of a stem and roots occasionally presents itself, yet these seem to have no other function than to give the means of attachment to the leaf-like expansion, which performs not only the nutritive but the reproductive function (§ 520, 521) on all parts of its surface. In the LICHENS, there is altogether a great similarity of form and structure to the Algæ; but the difference in their locality appears to produce a separate appropriation of portions of the surface to the nutritive and reproductive functions. The upper surface of these plants, being exposed to the sun and air, becomes hard and dry, a condition which seems to favour the evolution of the fruit; whilst it is by the lower surface, which is usually soft and pale, that the nutriment is probably introduced into the system. The latter is not unfrequently furnished with hair-like appendages, which may be regarded as prolongations of its surface; and these not only serve to fix the plant, but appear to be much concerned in the absorption of its aliment, being so much developed in some Lichens which are located upon the ground as almost to resemble roots. In the FUNGI we find a still smaller portion of the general surface adapted to absorb fluid, and more especial prolongations of it for the purpose. The lower forms of this group (§ 64), however, seem to imbibe their aliment by their whole surface; but in the more complex structures, the reproductive system is separated from the nutritive by the intervention of a stalk (as in the Mushroom), whose base is prolonged into hairs or radical fibres, by which the decaying matter, that constitutes the food of this remarkable group of plants, is introduced into the system. In some species, too, the whole surface is covered with hair, which may assist their very rapid development by absorption of fluid from the atmosphere.

247. In the MOSSES and their allies we find a somewhat higher form of the same structure. From the base of the stem there usually proceed slender radical filaments, which sometimes ramify through the soil to a considerable extent; and other similar filaments are frequently developed from the sides of the stalk, and from the lower surface of the leaves. In Mosses that exist on rocks, however, these filaments are but little developed, and appear to serve rather for support than for absorption of nourishment, which must in such circumstances be derived from the atmosphere through the leaves. It is well known that these are very permeable to fluid, and that Mosses will thus recover the appearance of life after being long dried; from the same cause, these beautiful little plants are enabled to vegetate rapidly during a moist season, whilst their tenacity of life enables them to withstand a subsequent drought. In ascending through these tribes of the Cryptogamia, then, we may trace a gradual development of separate absorbent organs, and may observe the *specialisation* of the function, by its restriction to one particular part of the

surface, instead of being diffused over the whole. Still, however, we find that when these special organs are not developed, or are insufficiently supplied with nutriment, the general surface can take on its original function and thus supply the deficiency.

248. It is probable that in all the Cryptogamia, except the Ferns (which, possessing a *vascular* structure, seem to resemble flowering plants in the essential conditions of their nutrition,) the whole surface of the radical fibre is endowed with the power of absorption; in the PHANEROGAMIA, however, it seems to be through the newly-formed, succulent extremities alone that fluid is admitted; and the function is, of course, more actively performed by them in proportion to the diminution in the amount of surface they expose. The root presents a great variety of forms in different plants; there are, however, some parts which are essential, and others merely accessory. The simplest form, as well as the most essential part, consists of single fibres; these occasionally exist alone (as at the base of the hyacinth bulb), but more often proceed from ramifying branches of woody texture (as in most trees and shrubs), or from tubers (as that of the turnip). Each fibre appears to differ from those just mentioned as existing in cellular plants, by the possession of a bundle of vessels which occupies its centre: and the extremities of these tubes are covered with loosely formed cellular tissue, through which it appears that fluid passes into them. This structure is well seen in the radical fibre of *Lemna* or *duckweed* (Fig. 76). The *spongiole*, as this point has been termed, is sometimes spoken of as a distinct organ; but it is nothing more than the growing point of the root, which, with a few exceptions, lengthens only by additions to its extremity. The soft lax texture of the newly-formed part, causes it to possess in an eminent degree the power of absorption; but as the fibre continues to grow, and additional tissue is formed at its extremity, that which was formerly the spongiole becomes consolidated into the general structure of the root, and loses almost entirely its peculiar properties. That it is to the spongioles that the principal absorbing power of the root is due, was fully proved by the experiment of Senebier. He fixed two roots in such a manner that the extremity of one was in contact with water, whilst of the other every part except the extremity was immersed. He found that the first root absorbed nearly as much as usual, whilst the second scarcely took up a sensible quantity. It is not improbable that the relative absorbent power of the spongioles and of the general surface of the root may vary in different plants, according to the character of the texture of each, and the situation in which it grows; but it appears to be a general fact that in vascular plants the spongioles are the organs *specially* destined for introducing the fluid nutriment into the system.

249. There are evident limits to the supply of alimentary materials to the roots of plants, as long as they remain in the same spot; and some change must take place to ensure its continuance. As the plant cannot

remove itself to a new situation, its wants are provided for by the simple elongation of its radical fibres; and their extension takes place, not by increase throughout their whole length, but by addition of fresh tissue to their points. This addition, being made in the direction of least resistance, enables the fibrils to insinuate themselves into the firmest soil, and even to overcome the obstacle presented by solid masonry; for however narrow the crevice may be into which the filament enters, the subsequent expansion of the tissue by the infiltration of fluid is so great, as to enlarge the opening considerably, and even to rupture masses of stone. This tendency to increase in the direction of least resistance, will also evidently cause the root to grow towards a moist situation; and by keeping this in view, many of the facts regarding the so-called *instinct* of plants, which at first sight appear so remarkable, may be satisfactorily eplained. There are some cases, however, for which our present amount of knowledge does not enable us to account.

250. The absorbent power of the spongioles appears limited by the size of their pores, which, although hitherto undetected, must have a sensible diameter. If the roots be immersed in coloured solutions, they take up the most finely divided particles, leaving behind the larger molecules, which are only absorbed when the spongioles have been damaged. The pores are liable to be blocked up by fluids which are of too viscid or glutinous a consistence to pass readily through them; and if the roots are immersed in a thin solution of gum or sugar or neutral salts, the watery particles are absorbed in the greatest degree, so that the portion which is left contains a larger proportion of the ingredient in solution. The power of *selection*, however, would seem to extend beyond this; since of two substances equally dissolved, some plants will take one, and some the other; and some neutral salts are rejected altogether. It does not appear that the selecting power is employed to prevent matter from being introduced into the tissue of the plant, which is capable of exerting a deleterious influence upon it; for many substances are taken up by the roots, which speedily put a stop to vital action, if opportunity is not afforded for their excretion. From the little that is at present known on the subject, it seems a reasonable inference that the rejection of any particular ingredient of the fluid in contact with the roots, results either from the want of adaptation in the form or size of its molecules to the pores of the spongioles; or from an organic change effected by it on their delicate tissue, such as is proved by the experiments of M. Payen* to occur when tannin enters into the solution, even very minute proportion.

251. The *quantity* of fluid absorbed, and the force with which it is propelled upwards in the stem, vary not only in different species and individuals, but in the same plant at different perids of the year and even of the day. The former seems intimately connected with the activity with which the other processes of vegetation are being carried on, and especially

* Ann. des Sci. Nat. N. S. Botan., vol. iii. p. 5, &c.

to depend upon the quantity of vapour transpired from the leaves (CHAP. X.); all the causes which increase transpiration may therefore be considered as stimulants to absorption also. The force of the roots in the propulsion of the sap is sufficiently proved by the celebrated experiments of Hales on the vine. By gages affixed to the stem during the "bleeding season," when the sap rises rapidly, he found that a column of mercury 26 inches high, equal to a column of water nearly 31 feet, might be supported by the propellent force of the absorbent organs; but if the upper part of the plant was cut off, this power soon diminished, and after a time ceased altogether.

252. There would seem much reason to believe that the mere act of Absorption, in this and other cases, is due to the physical property already referred to as possessed by many organised tissues,—viz. the capability of producing endosmose (§ 244). The succulent extremities of the spongioles serve as the medium required for this process; but it may be reasonably enquired whence the other condition is furnished, namely that difference in density of the fluids on the opposite sides of the septum, which is necessary for the commencement and continuance of the action. This is, in the first instance, supplied by the store of nutritious matter obtained by the embryo from its parent, and contained within its tissues; and, at a later period, when the plant is supporting an independent existence, by the admixture of a portion of the dense elaborated or descending sap, with the crude and watery ascending fluid. If this be the true explanation of the phenomenon, a counter current ought to exist, and an *exosmose* of the fluids within the system should take place into the surrounding medium. That this is actually the case is proved by the fact that an excretion of the peculiar products of the species may be always detected around the roots of the plant (§ 454); a fact of very important practical applications. The cessation of this action of admixture (a change evidently depending upon other vital actions) at the death of a plant, fully accounts for the non-continuance of endosmose, which is also checked if the superincumbent column of fluid be not drawn off by the leaves. It has been very justly remarked by Professor Henslow that "if we suppose the plant capable of removing the imbibed fluid as fast as it is absorbed by the spongioles, then we may imagine the possibility of a supply being kept up by the mere hygroscopic property of the tissue; much in the same way as the capillary action of the wick in a candle maintains a constant supply of wax to the flame by which it is consumed."*

253. It is an axiom in Vegetable Physiology which has been laid down by De Candolle "that when a particular function cannot, according to a given system of structure, be sufficiently carried into effect by the organ which is ordinarily appropriated to it, it is performed wholly or in part by another." This is but a result of the general principle which has been

* Cabinet Cyclopædia. Botany. Page 177.

already laid down (§ 201); and the reason that it is more evident in the Vegetable than in the Animal kingdom is simply, that in the former the specialisation of function is nowhere carried so far as in the latter; so that any part of the general surface of a plant can perform in a considerable degree the functions of all the rest. We might then *a priori* expect that whilst the roots are, in the usual condition of the perfect plant, the organs by which its fluid nutriment is absorbed, and the leaves its organs of transpiration and respiration, some traces of the primitive community of function enjoyed by the general surface of the simpler tribes, would be found in the capacity of each of these organs to perform in a certain degree, if required, the function of the other. Thus, it is evident that when the roots are either absent or imperfect, or are implanted in an arid or barren soil, serving merely to fix the stem (as happens with many *Orchideæ* and the generality of aerial parasites), the plant must derive its chief supply of nutriment through the absorption performed by the leaves, or in leaf-less plants (as the *Cacti*) through the general surface. And it must be obvious to all who have observed the manner in which plants faded by the intense action of light and heat are refreshed by the natural or artificial application of moisture, that absorption takes place, in these instances also, by the general surface, as well as by the roots.

254. Various experiments have been devised with the view of determining the relative extent to which the plant is supplied by these two channels; but the proportion appears to depend upon the circumstances of its growth. Thus, Bonnet took some specimens of Mercurialis, and immersing the roots of part of them in water, he placed others so that only their leaves touched the fluid. A small shoot of each plant was kept from contact with water, and after the experiment had proceeded for five or six weeks, those which had derived all their nutriment through the leaves were nearly as vigorous as those which had imbibed it by the roots. It is by the under surface of the leaf, where the cuticle and cellular tissue beneath are least compactly arranged, that absorption is performed with the greatest rapidity; and the downy hairs with which some plants are plentifully furnished seem to contribute to this function, acting like so many rootlets. These prolongations of the surface are usually wanting in such plants as grow in damp shady situations, where moisture already exists in abundance; but in hot, dry, exposed localities, where it is necessary that the plant should avail itself of every means of collecting its food, we find the leaves thickly set with them; and this difference may be observed in the same species of plant according to the soil and climate in which the individuals exist, and even in the same individual if transplanted. A very curious adaptation of the leaf of the Oleander to the same purpose will be hereafter described (§ 428).

255. In tracing the gradual evolution of the special absorbent system of the more perfect plants, we may observe many interesting relations

between the progressive stages of its development, and the permanent forms of the system in the lower orders. Thus, the embryo at its first appearance within the ovule (§ 525, 6) is nothing but a single cell, like that of the *protococcus*, in the midst of the store of semifluid nutriment prepared by its parent, which it gradually absorbs by its whole surface, just as do the simplest cellular plants. At the time of the ripening of the seed, we find the rudiment of the future root, which is developed during germination; but in the early stages of this process, the radicle simply prolongs itself into the ground, and appears to be equally capable of imbibing moisture thaough its whole length, like that of the Fungi or Mosses. It is not until the true leaves are evolved, that the root begins to extend itself by ramification, then first protruding perfect fibrils, composed of woody fibre and vessels, and terminated by spongioles.

256. Thus, then, in the development of the absorbent system of vegetables, the first which we have been called upon to study in detail, we have perceived the application of the laws which have been already enunciated (CHAP. III.); for it has been found that whether we trace its various forms through the ascending scale of the different tribes of plants, or watch the progress of its evolution in the more perfect orders, it is constantly to be observed that the *special* structure and function arise by a gradual change out of one more *general;* and that even where the *special* form is most highly developed, the *general* structure retains, more or less, the primitive community of function which originally characterised it.

Digestion and Absorption in Animals.

257. It has been already stated that the conditions under which the function of Absorption is performed in animals, are so far different from those which affect it in plants, that a preparatory process of *Digestion* becomes necessary for the reduction of the food to the fluid form required for its entrance into the system. This process is effected in cavities of the body, which are bounded by a continuation of its external surface, modified, by its secreting power, to supply the means necessary for the solution of the aliment, and, by its absorbent faculty, for the selection of the part of it capable of contributing to the nutrition of the fabric. It has been already shown that so long as this aliment is unabsorbed, it cannot be regarded as introduced into the system; since it merely holds the same relation with the absorbent vessels, as the nutritious fluid surrounding the roots of plants. Both are liable to be influenced by the secretions poured out from the surfaces with which they are in contact; and though we have no positive evidence that vegetables ever prepare their food by such means, its occasional employment may be inferred from the fact, that the Fungi have been observed to hasten the decomposition of substances on which they have made their appearance. The chief peculiarities, then, in the preparation of the food of Animals, consist in the mechanical

influence to which it may be subjected, by the peristaltic and masticatory actions of the alimentary canal and its appendages; and, in the temperature to which, in the higher animals at least, it is subjected. With the process of absorption, strictly so called, the organisation of the constituents of the alimentary fluid, and their endowment with vital properties, may be regarded as commencing in animals as well as in plants.

258. That the process of digestion has really this character,—that it is no more dependent upon the *vital* powers of the stomach, than as far as these are concerned in the secretion of its solvent fluid, and the maintenance of its temperature and movements,—appears from the most recent experiments, as well as from *a priori* reasoning. For, as will presently be stated, the gastric juice seems to be as energetic out of the stomach as in it, provided that the other conditions, namely, the warmth and the motion, are also supplied (§ 261); and, where sudden death takes place in an healthy animal, the stomach itself is not unfrequently dissolved, if it be not distended with food on which the solvent will more readily act. This seems to be an unanswerable argument in favour of the simply *physical* nature of the process of digestion; since it is absurd to suppose that any lingering vitality in the organ itself can have an influence in disorganising its own tissues.

259. The first act in the digestive process is the mechanical reduction of the food which has been ingested, to a state which will render it more easily affected by subsequent chemical processes. This is accomplished by the acts of mastication and insalivation, for which provision is made in most of the higher classes of animals. Mastication is not always, however, performed in the mouth; for though that is the situation of the teeth in Mammalia and Reptiles, the *pharynx* (or funnel-like entrance to the gullet) is their seat in Fishes, and the stomach in Crustacea. A gizzard, or hard muscular stomach with cartilaginous walls, answers the purpose of mastication in graminivorous Birds, Cephalopoda, and probably also in the higher Polypes (§ 117); and in the first of these classes, insalivation is performed, not in the mouth, but in the *crop*, a dilatation of the œsophagus in which the food is retained for this purpose. In general it will be found that the more analogous is the character of the food to that of the animal juices, the less preparation of this kind does it undergo. Thus, the carnivorous Mammalia have teeth and jaws more adapted for cutting and tearing than for mastication; whilst the herbivorous species, which are deficient in teeth of that character, have the remainder so constructed as to present a large uneven surface for the trituration of their aliment, and jaws capable of that peculiar rotatory movement which can give most effect to their employment. In Birds, again, the predaceous species are destitute of any mechanical means of reducing their food to the semifluid state which vegetable substances must acquire before they can be acted on by the gastric juice; and the

only preparation which it undergoes, is the separation of the hair, feathers, claws, and other indigestible parts, which are disgorged from the crop without being allowed to pass through the alimentary canal.

260 There are many animals for whose food such preparation does not seem necessary; its soft consistence and high organisation (which increases its tendency to decomposition) rendering it easily soluble. Such are the whale, which is destitute of teeth, and whose gigantic swallow is furnished with an enormous filter for straining off those minute inhabitants of the ocean of which such myriads are necessary for its subsistence; and there are many Mollusca, and even animalcules, which, in their mode of obtaining their food, as well as in the voracity of their appetites, seem like whales in miniature. Whether or not the saliva, which in most animals that masticate their food, is mixed with it during the process, has any other than a mechanical agency, is not fully ascertained; many have imagined that it possesses a solvent power on the organised substances through which it is diffused, superior to that which water alone would exercise; but the only fact known on this point is that it has the property, like gastric juice, of changing starch into sugar.

261. Various experiments have been made at different times on the solvent power of the gastric juice, and on the influence of the motions of the stomach on its effects; but none are so satisfactory as those of Dr. Beaumont, who availed himself of the opportunity afforded him by the remarkable state of Alexis St. Martin (a man who, though in perfect health, had a fistulous opening in his left side, which permitted inspection of the interior of the stomach, and the removal of its solid or fluid contents), to settle many points which previous contradictory statements had left doubtful, as well as to add much to what was already received. The food which has been propelled down the œsophagus enters the cardiac orifice of the stomach in successive *waves;* and there it is subjected to a series of operations, of which chemical solution is undoubtedly one of the most important. The *gastric juice* by which it is effected, is poured out of minute follicles or secreting cavities in the coats of the stomach; but some animals, whose food is peculiarly difficult of digestion, appear provided with a more special glandular apparatus for its elaboration, such as exists in the Beaver (§ 459). This fluid is secreted only when the coats of the stomach are irritated by the contact of matter ingested by it; and it can therefore only be obtained in a pure state, by introducing some insoluble body which shall cause its formation, and shall also absorb it as fast as it is poured out. For this purpose a piece of sponge has been frequently employed, which has been swallowed, and when saturated, has been drawn up by a thread fastened to it; but Dr. Beaumont was enabled to accomplish the same object in a more satisfactory manner by introducing an India-rubber tube through the opening,

which served both to irritate the membrane by its contact, and to conduct away the fluid as fast as secreted, without admixture. The gastric juice thus obtained was found to have a reducing power but little inferior to that of the stomach itself, when its solvent action was assisted by heat and agitation; and a homogeneous fluid, closely resembling the *chyme* of the alimentary canal, was produced by these means. Similar effects have been obtained by an *artificial* gastric juice, which has been formed (by Müller and Schwann) of a mixture of dilute acetic or muriatic acid with mucus of the stomach; the simplest way of manufacturing it being, to macerate a portion of mucous membrane in the acid. But this, although it appears effectual with many substances, is resisted by others. Neither acids nor mucus, however, will act alone; but the correspondence of their united effect, so far as it goes, with that of the gastric juice, can leave no doubt that the operation of the latter is of a chemical nature.

262. The *chyme* thus formed is not absorbed without further preparation; and it is in the separation of the portion of it which will become subservient to nutrition, from that which is only fit for rejection, that the operation of the bile seems most important. Dr. Beaumont mentions that a mixture of biliary and pancreatic secretions (both of which he was able to procure by means of his elastic tube) with chyme,. separated the latter into a turbid milky fluid, which he regarded as chyle, and a flaky precipitate, which appeared of an excrementitious character. Of the nature of the changes which the food undergoes in its progress along the intestine, we know, however, but very little. The nutritious portion is gradually taken up by the absorbent vessels, which are distributed copiously on the mucous lining of the tube. In the Invertebrata, it would appear that ~~that~~ the general vascular system performs this office, the absorbed fluid at once entering the current of the circulation; but, in higher animals, a more special provision for this purpose is observed, in the system of *lacteal absorbents*, which are delicate vessels distributed on the mucous surface of the intestine, and destined for this function alone. The fluid which they absorb, termed *chyle* (which will be described hereafter § 357) is conveyed in a general receptacle, where it is mixed with the lymphatic fluid absorbed from the system at large (§ 331); and both then enter the general circulating mass. These absorbent vessels may be regarded as strictly analogous to the roots of plants. They do not open by patulous orifices on the surface of the intestine; but ramify among the *villi* of the mucous membrane, which are little filamentous processes of delicate structure, that give to its surface the fleecy appearance it exhibits when highly magnified. In Fig. 103 is seen one of these villi with its absorbent vessel, which may be contrasted with the absorbent termination of the radical fibres of plants formerly described (§ 248 and Fig. 76). It is only in the higher animals, however, that these villi exist; in the lower tribes, the surface of the membrane is increased by its being plaited

into simple folds; or it may be altogether smooth,—but its extent is then proportionably greater.

263. It is curious to observe, in the progress of the food along the alimentary canal of higher animals, the gradual removal of it from connection with the functions of *animal* life. To procure it in the first instance, is one important office of these functions; and the highest exercise of the locomotive, sensorial, and intellectual powers is often required for this purpose. Its introduction into the mouth is an act of pure volition in man, whilst the masticatory movements to which it is there subjected may be regarded as having been originally voluntary, but as afterwards so completely habitual as to be scarcely dependent on the will, although not removed from its control. The act of *deglutition* or swallowing is of a very curious nature, being the result of a nervous influence in which the will is not concerned: when the solid or fluid contents of the mouth are brought in contact with the surface of the pharynx, the impression made upon the sensory nerve is transmitted to the upper part of the spinal cord; and an instinctive motor impulse is propagated along the motor fibrils, by which the muscular movements requisite for the action of swallowing are excited. How far this process necessarily involves consciousness and sensation on the part of the animal will be hereafter enquired (CHAP. XVI.). A similar action causes the propulsion of food down the *œsophagus* (gullet); and the movements of the stomach are in part, if not wholly, excited in the same manner. Beyond the stomach, however, the connection of the motions of the alimentary canal and the nervous system ceases, the peristaltic movements of the intestines appearing to depend upon the stimulus directly applied to their muscular coat by the contact of food; although they may be in some degree controlled by a system of muscles disposed around the outlet of the canal, which are, like those at its entrance, partly involuntary, and partly under the direction and restraint of the will.

264. In the lower animals, however, the process is much more simple. The very action of introducing the food into the stomach appears to be, in many instances, the result of direct stimulation, without the intervention of a nervous system. Thus, the movement of the *cilia*, which fulfils this purpose in so many animalcules, is known to be completely involuntary and unproductive of sensation in higher tribes; and analogy would seem to show that the contraction of the tentacula of the Hydra and other polypes, is of no higher character (§ 115). Where the nervous system is first distinctly concerned in such actions, it is probably only in combining and harmonising them; and as long as they are constant and uniform, always occurring under the same circumstances, and excited by the same stimuli, it seems more philosophical to regard them as purely instinctive, like the action of deglutition in man, and as not of themselves implying anything like *will* on the part of the animal, which can only exist where

there is intellect.* A brief sketch may now be given of the principal forms of digestive apparatus in the different classes of animals; but the extent of this subject renders it necessary to enter but little into details.

265. The class PORIFERA presents us with what may be regarded as the same simple form of an absorbent system as that which prevails among the Algæ. Every part of the surface of the soft gelatinous flesh of the Sponge, appears equally endowed with the power of appropriating to itself the nutritious materials contained in the water which is in apposition with its external surface and circulates through its ramifying canals. These canals constitute the simplest means by which the absorbent surface may be increased without prolonging them externally; and the movement of fluid through them may be regarded as uniting the capillary circulation of the higher animals with the propulsion of food over the absorbent surface of the intestinal tube,—a special circulating apparatus not being here interposed between the part of the system where the fluid is absorbed, and that in which it is applied to the purposes of nutrition (§ 281). The small quantity of alimentary materials contained in the waters of the ocean, renders necessary in this class a rapid and continuous ingestion of successive portions; and as the animal does not possess the power of appropriating solid masses to the supply of its wants, there is no necessity that the food should be delayed in digestive cavities, for the purpose of undergoing any change preparatory to its absorption. Minute flocculent films may be observed in the fluid which issues from the vents or fœcal orifices; and these may be regarded as composed of excrementitious particles thrown off from the interior surface.

266. The method in which the *Hydra* and other POLYPIFERA obtain their food, presents a remarkable contrast to that just described. The sides of the digestive cavity are probably endowed, in most of these animals, with an equal power of absorption throughout; but the food is generally introduced in solid masses, frequently in a living state, and must long be submitted to the influence of the digestive process before it can be

* It may be said that although the tentacula of the Hydra, when the animal is hungry, contract upon the slightest touch, they allow themselves to be stimulated without responding, after repletion with food; and that sensation and will are thus implied. But, on the other hand, it may be urged that a parallel phenomenon occurs in man, which is certainly independent both of will and sensation. For it appears from the experiments and observations of Dr. Beaumont, that the secretion of gastric juice does not continue in proportion to the quantity of food taken into the stomach, although at first excited by its contact, but to the wants of the system; so that when sufficient nutriment has been provided for absorption, no further active process of digestion goes on, although the *will*, inattentive to the dictates of Nature, continues to transmit to the stomach more food than is dissolved at the time. Vegetables, again, cease to absorb when the structure is replete with food, and there is no continued demand for it. The more we pursue our researches into the actions of plants and of the lower tribes of animals, the more are we struck with the beauty of the adaptations by which the influence of a capricious will, which would often be to the injury of the system, is rendered unnecessary.

assimilated. In these two classes, then, we have two opposite characters of the digestive apparatus distinctly exhibited:—in one the food is already introduced into the cavities in a fluid form (as in plants), and so largely diluted that no further preparation for its absorption is necessary, all that is required being a continued supply of it;—whilst in the other, the food is obtained at distinct intervals, and in a form which requires energetic digestive actions to render it fit for absorption. In the Hydra, the transparency of the tissues, and the absence of any firm envelope, allow the process to be distinctly watched. The prey is frequently, and indeed generally, introduced alive; and its movements may be observed after it has been swallowed. In a little time, however, its outline appears less distinct, and a turbid film partly conceals it; the soft parts are soon dissolved and reduced to a fluid state; and any firm portions which the body may contain, are rejected through the aperture by which it entered. When the process of digestion is complete, the granules, of which the texture of the animal seems principally composed (§ 115), are observed to be tinged with the colour of the dissolved substance, although the fluid which surrounds them remains transparent. A movement of these granules seems concerned in the distribution of the absorbed matter through the fabric; sometimes they are seen to be forced into the tentacula, whence they are driven, by a sort of reflux, back to the body.

267. In the associated species of Polypifera, there is considerable diversity in the degree in which the functions of the individual Polypes are connected together. In many of the simpler *Alcyonians* (§ 119), which are, like Sponges, provided with polypes at their orifices, a general circulation of the products of digestion takes place through the whole fabric. The same is the case, although to a less extent, in the Sertularia and other *Hydraform* Polypes, as already mentioned (§ 116); while in the complex *Ciliobrachiata*, each Polype seems to live for itself alone (§ 117). The digestive process exhibits itself in the latter with a considerable advance towards its more perfect types; for we find not only a second orifice to the alimentary tube, but a gizzard for mechanically reducing the food, a secreting apparatus for the production of bile, and a distinct separation of the stomach from the lower part of the intestinal canal. This conformation evidently conducts us to the highly-developed digestive system of the Mollusca; whilst in the isolated *Actiniæ* (§ 120), we are led towards the Radiata. The stomachs of these animals are very capacious and distensible; so that, like the *hydra*, they can enclose prey many times larger than themselves, which their copious secretions enable them speedily to dissolve, the excrementious matter being thrown out by the oral orifice. The ramifying tentacula of these animals, which surround the central disk containing the stomach, remind us of the minutely-divided arms of the *Comatula* and other stellated species of Echinodermata, into which the digestive cavity does not extend (§ 107, 270).

268. The number of the digestive sacs in the class POLYGASTRICA has already been noticed (§ 114) as its distinguishing characteristic, and some of their forms detailed. In the *Monas*, a minute animalcule, formerly supposed to be destitute of any cavity whatever, several stomachs open into a common mouth, surrounded by cilia (Fig. 93); but, in most other species, the digestive sacs are connected with a tube which has an equal relation to all (Fig. 77, *a*). No special absorbing organs are yet developed in these soft-bodied creatures; and the extension of the alimentary canal through the whole system, by which the nutrient materials are directly conveyed to every part, seems to prevent the necessity for any such provision.*

269. Among the ACALEPHA, the digestive system, although formed upon a simple type, exhibits a very complex arrangement. In the *Medusa* (Fig. 89), the mouth, situated on the lower surface of the disk, in the centre of the four tentacula, leads to a capacious stomach, partly divided into four portions by the ovarial sacs, which have separate external orifices. From this central cavity, prolonged canals ramify minutely through the tissues, and are especially distributed on the margin of the mantle, where the aeration of the fluid seems principally effected. In other species, such as the *Rhizostoma*, the stomach has no large orifice, but imbibes its fluid by vessels contained in the tentacula, and opening by minute pores on the surface; before these openings were discovered, the cavities were supposed to be filled by endosmose. The ramifying canals are here even more complex, and are distributed most minutely on the free margin of the mantle, the propulsive movements of which evidently assist in its aeration. Here we perceive an enormous extension of the digestive cavity, compensating for the absence of a special vascular system, which is not yet developed. In the *Beroe* (Fig. 90) and other allied species, there is

* The account of the digestive apparatus of Polygastrica given in the text is based upon the statements of Ehrenberg. The author is much disposed, however, to agree with Professor Rymer Jones (Outline of the Animal Kingdom, p. 57) in questioning the correctness of these observations. The belief in the existence of a number of distinct sacculi opening from a common intestinal tube, is founded upon the appearance of animalcules which have been fed with coloured particles, and which exhibit numerous coloured globules in their substance, that have been supposed to be cavities into which the matter from without is immediately introduced by the canal proceeding from the mouth. "During the last two hours," says Prof. J., "we have been carefully examining some beautiful specimens of the *Paramœcium aurelia*, an animalcule which, from its size, is peculiarly adapted to the investigation of these vesicles; and so far from their having any appearance of connection with a central canal, they are in continual circulation, moving slowly upwards along one side of the body, and in the opposite direction down the other, changing moreover their relative positions with each other, and resembling in every respect the coloured granules which have been described as visible in the gelatinous parenchyma of the Hydra" (§226). With regard to one rare animalcule, the *Enchelis caudata*, which recently came under the author's notice, he is fully convinced that it possesses a single large cavity like that of the Hydra; this he has seen partly filled with the green *Cercariæ* which the creature had devoured, and he was at the same time able to trace distinctly the boundaries of the empty portion of the digestive sac, which occupied nearly the whole body.

an alimentary canal passing through the body, with a capacious dilatation, serving as the stomach, which sometimes occupies nearly its whole bulk. When there is no food in it, both orifices remain open; and as the animal swims with its mouth forwards, a constant current of water is passing through: but when alimentary matter touches the walls of the stomach, its orifices are immediately contracted, and the digestive process begins. Ramified biliary follicles appear to surround the stomachs of some of the higher species, assisting the process of digestion by the secretion they form.

270. Among the ECHINODERMATA, we find an important addition to the digestive system, in the development of a distinct circulating apparatus; and in proportion to the perfection of this do we observe the absorbent surface diminished, as in plants. In the common *Asterias*; the stomach has but one orifice, and not only occupies the central disk, but sends cœcal prolongations into the rays. Upon these we find the absorbent vessels, which may be regarded as *veins*, minutely ramifying. In the *Comatula* and *Pentacrinus*, these cœca are rudimentary, the stomach being confined to the disk; and this also contains two convolutions of a cylindrical intestine, which terminates by a separate orifice near the mouth. Rising through the Clypeaster and Spatangus (§ 107) to the *Echinus*, we observe the two orifices becoming more and more distant, until, in the last, they are situated on opposite sides of the body. In the *Holothuria*, as in the Echinus, the intestinal tube varies little in diameter from one extremity to the other; in some species we find not only biliary but salivary follicles; and the absorbent veins are distributed on the intestine through the *mesentery*, or membrane which binds it to the walls of the general cavity of the body. The firm tegument of these animals must almost, if not entirely, check that absorption of fluid through the exterior surface, which, in the classes previously mentioned, appears to perform a most important part in nutrition.

271. There is considerable uniformity in the structure of the digestive apparatus throughout the sub-kingdom ARTICULATA. It usually partakes of the character of the body itself, being elongated and narrow, with little dilatation in any part; this is in conformity with the general habits of the group, which are carnivorous; and it will be found, here as elsewhere, that the more highly organised is the food, the more simple is the apparatus required to reduce it. In all but the very simplest ENTOZOA (which in the present arrangement have been consigned to the group of Acrita), there are two orifices to the alimentary canal; and these are situated near the opposite extremities of the body. In some of these, however, the head, which is generally furnished with curved spines or hooks, does not appear so much concerned in the nutrition as in the attachment of the animal; and nourishment seems more derived by general superficial absorption, than by the mouth. As long, in fact, as

the integument remains soft, and the alimentary surface unprovided with definite absorbent vessels, the former seems almost as important to nutrition as the latter. In these parenchymatous worms, therefore, we return to the simplest condition of the nutritive apparatus, in which the aliment is brought into immediate relation with the tissues to be supplied. It is very interesting to remark that, in some of the lowest of the Vermiform tribes, the entrance to the digestive canal is not by one orifice but by several, which seem to act as so many polypes among Zoophytes. In the *Tænia* (tape-worm), there are four of these, leading to two canals which remain separate during their whole length, but are connected by transverse canals in each segment.

272. In the higher species of Entozoa, as most of the other Articulata, we find a vascular system superadded to the digestive, and thus superseding the necessity of the ramification of the latter through the body. The intestine not being in them merely channelled out of the tissues, but having the character of a distinct tube, is attached to the walls of the cavity in which it lies, by a *mesentery*, as in the higher Echinoderma; and in this, the absorbent vessels, which form as yet only a portion of the general vascular system, are distributed to its surface. In Fig. 111 are shown, on one side the digestive system, and on the other the vascular apparatus, of the curious *Diplo-zoon paradoxum*, a parasite infesting the gills of fishes. In some of this class we observe the first rudiment of a liver, in the *cœca* (tubes closed at one extremity) which are prolonged from the intestinal canal. These are observed gradually to become more numerous, as we ascend the scale, and to open into some definite point in the alimentary tube, which is always in the neighbourhood of the dilatation that may be regarded as a stomach, where such exists. At the same time we find masticating organs superadded, which are furnished with rudimentary salivary glands, having a similar cœcal form, like those of the Echinus. Some of these parts are represented in Fig. 104, which shows the jaws, *a*, *a*, stomach, *b*, and biliary cœca, *c*, *c*, of the *Diglena lacustris*, one of the ROTIFERA (§ 93). In the ANNELIDA, and MYRIAPODA, the alimentary canal usually retains its straight form, but exhibits, in the higher orders at least, a more definite separation into parts. The mouth gradually becomes more complex in structure, being endowed with distinct organs for mastication or for suction; the œsophagus is usually narrow, and then dilates into a larger cavity—the stomach,—which is frequently provided with a firm muscular coat, like the gizzard of birds. Below this, the intestine is usually narrower, but sometimes dilates again near its termination, as in higher animals. Where the canal is more uniform in size throughout, as in the leech and earthworm, the biliary cœca are short and numerous, and disposed along nearly its whole length, instead of being restricted to the neighbourhood of the stomach. They may always be distinguished,

however, as secreting organs, from such prolongations of the digestive cavity itself as we observe in the Asterias; since the contents of the tube are never seen to pass into them, and they exhibit the yellow colour peculiar to their secretion. It might be expected from the general Molluscous form and condition of the CIRRHOPODA that the characters of their digestive system should assimilate with those exhibited in that division. This is indeed the case; for we here find a development of the salivary glands and liver quite disproportionate to the general perfection of their structure as Annulose animals,—these organs, as we shall presently see, being evolved in the Mollusca in the inverse proportion to their possession of animal powers.

273. In INSECTS we find the digestive apparatus presenting nearly the same characters as in higher animals; and the variations in its conformation which adapt it to the respective kinds of food upon which the different species exist, are extremely well marked. The two modes in which food is obtained in this class, have already been noticed (§ 89); but it may here be added that in each case the mouth is constructed of the same parts, which form either *mandibles* armed with teeth for cutting and tearing, or a long delicate *proboscis* for suction, according to the requirements of the animal. These parts often change their form during the metamorphosis, when the food of the *imago* differs from that of the *larva*. Where the food is subject to much trituration in the mandibles, the salivary glands are large; but they still exist only in the condition of prolonged cœca (CHAP. XI.). The œsophagus (*a*, Fig. 105) is usually narrow above, and dilates below into a *crop*, *b*, which, like that of birds, seems destined to commence the digestive process by macerating the food in the fluid secreted by its follicles. Below this is a muscular stomach or *gizzard*, *c*, for mechanically reducing the food; but the development of this depends on the nature of the aliment, and it is altogether absent in those which live by suction. The true stomach, *d*, however, is never wanting, and is always distinctly separate, in the adult state, from the rest of the canal. It is surrounded by biliary cœca, which usually open near its termination. The form and size of the lower intestine vary much in different species; being straight and narrow in carnivorous insects, and convoluted with occasional dilatations in the vegetable-feeders. In most adult insects, we observe very long convoluted and often branched cœca, *e*, *e*, which open into the intestinal canal, at a variable distance between the stomach and its termination. These have been usually regarded as analogous to the liver; and yet their entrance below the part where digestion was proceeding, seemed incompatible with what is known of the uses of the bile in other instances. It has been shown, however, by analysis of their contents, that they are to be regarded as urinary organs; and that the fluid they pour into the canal is strictly an excretion, as the position of their

orifice would indicate.* The digestive apparatus of the ARACHNIDA and CRUSTACEA, which are all carnivorous, resembles that of the predaceous insects, in the shortness and simplicity of the alimentary canal; and the dilatations on it are nowhere considerable. The liver now begins, however, to assume a more concentrated form, the follicles and cœca being aggregated into lobules of solid appearance (§ 459); and in the higher Crustacea the entrance to the stomach as well as the mouth is guarded with teeth, which are moved by powerful muscles, and have a firm calcareous structure.

274. The development of the digestive system of the MOLLUSCOUS classes presents a remarkable contrast with that which we have been just considering. Whilst the generally acute sensations and active locomotive powers of the Articulated tribes enable them to go in search of their prey, and to select that which they are capable of digesting with the greatest facility,—the Mollusca are usually either fixed to one spot, or confined, by the want of means of active locomotion, within a very narrow range, and their perceptions seem proportionably obtuse. Being, therefore, dependent upon casual supplies for their support, their digestive organs are adapted to much greater variety of food, and to act upon organised matter of a kind much inferior to the tissues of the animals themselves. Even in the lowest of this group, we observe a form of the alimentary canal nearly as complex as that of Insects. Thus, in the *Cynthia*, one of the TUNICATA (Fig. 83), we see the œsophagus (the entrance to which, *c*, lies at the bottom of the sac of the mantle, into whose cavity water is constantly being received by the apertures, *a*,) leading to a wide stomach, *d*, surrounded by biliary follicles; and from this passes a convoluted intestine, *e*, which terminates, near the second aperture of the mantle, *b*, through which also are constantly being expelled the currents that have passed over the respiratory organs. The same character is evident in the CONCHIFERA; but the development of the glandular organs is greater; and the liver assumes a solid lobulated form. The aperture by which the surrounding water enters the mantle for the purpose of respiration, and for the supply of the digestive system, is here usually fringed with tentacula, and sometimes the rudiments of eyes are discernible in its neighbourhood. Among the GASTEROPODA we find a much more complex apparatus, expecially in the herbivorous species. The mouth is now situated on a prominent part of the body, and in the neighbourhood of organs of sensation. It is often furnished with jaws and a fleshy tongue, as well as with salivary glands; in the Limpet, the tongue, when extended, is longer than the whole body, and is covered with regular rows of sharp spines, which file down the coarse marine plants on which the animal feeds. The food is delayed in a *crop*, which is of very large size in the vegetable-feeders; after being

* Müller's Physiology, p. 519.

there macerated it is subjected to trituration in the small gizzard, which is often furnished with teeth, as in the Crustacea, and then transmitted to the third digestive cavity, or true stomach; this receives the secretions of the large lobed liver, and rudimentary pancreas, and is armed on its interior with sharp horny spines, which may serve to separate the food for its exposure to the action of these fluids. The intestine forms several convolutions round the liver, but does not again dilate considerably. The digestive system of the PTEROPODA does not essentially differ from this; nor, indeed, does that of the CEPHALOPODA, except in the higher development of its different parts, which present more of the forms exhibited in vertebrated animals. The liver, for instance, no longer consists of a number of separate portions covering the intestine, and opening into it by as many orifices; but it is a solid structure, completely separated from the walls of the digestive cavity, and pouring all its secretion into one tube, which conveys it to the intestine, its aperture being guarded by two valvular folds. The pancreas also assumes a more definite appearance (§ 458). The intestine in the naked species receives, near its termination in the *funnel* (*c*, Fig. 78), the duct of the ink-bag (§ 96), the secretion of which is so important to the protection of these animals; this may not improbably be regarded as analogous to the urinary excretion of the Vertebrata, since uric acid has been found to be secreted by a gland similarly placed in other Mollusca.

275. Throughout all the classes of VERTEBRATA, we observe a considerable elevation in the characters of the digestive apparatus, adapted to prepare nutriment for their highly organised bodies. In all instances there is a provision for the mechanical reduction of the food, either in the mouth or first stomach, the operation being assisted by a salivary apparatus; the hepatic and pancreatic secretions are formed by distinct glands of increasing complexity, and are poured into the intestinal tube just below the stomach, which always exhibits an evident dilatation; and the lower part of the intestine again widens into the *colon*, where an important part of the digestive process appears sometimes to be performed. But the most important change which we here find in its conditions, is the addition of a special system of absorbent vessels, designed to take up from the walls of the cavity the nutritious portion only of its contents. These vessels are termed *lacteals*, from the milky character of their contents; their origin and structure have been already described (§ 262); and their connection with the general absorbent system, and their termination in the circulating apparatus, will be hereafter shown (CHAP. VII.). It cannot be doubted that the absorption of *chyle*, or the nutritious fluid prepared by the digestive process, and separated from the excrementitious matter, is the *special* function of this system; and it seems well ascertained that its absorbent vessels exercise a power of selection like that of the roots of plants (§ 250), since many substances introduced into the intes-

tinal canal cannot be recognised in the chyle. But the general vascular system still retains in some degree that power which was restricted to it in the Invertebrata; for, though no longer concerned in the absorption of the nutritive contents of the digestive cavity, it seems to take up most of the extraneous matters which are introduced into the system, and to be the chief medium of the operation of poisonous agents. Although some of these may be detected in the chyle, as well as in the blood and the secretions from it, they probably enter the lacteals by the same kind of mechanical imbibition that causes them to permeate other tissues, and the absorption of them does not seem a part of the regular function of these vessels.

276. We find in the VERTEBRATA, as in the other divisions of the animal kingdom, a peculiarly well-marked distinction between those forms of the digestive apparatus which are adapted to reduce animal nutriment to the condition necessary for its absorption, and those which have to operate in the conversion of vegetable matter to the same state. These two forms might be contrasted with those respectively presented by the Articulated and Molluscous classes. In the former, the alimentary canal is short and simple, without any large dilatations; in the latter it possesses wide cavities for delaying the food and submitting it to the action of the digestive secretions; and the remainder of the canal is very much elongated, and disposed in convolutions, for the sake of bringing it within narrow compass. It is interesting to remark how the Annulose character may be traced both in the conformation and habits of many families among Vertebrata. Thus, among FISHES, we find the most simple alimentary canal belonging to those with elongated bodies, which obtain their food by sucking the juices of other animals. In the Lamprey, for instance, the whole intestinal tube from one orifice to the other is shorter than the length of the body, being perfectly straight, and having little dilatation. In some cartilaginous fishes, such as the Shark and Ray, the intestine appears straight externally; but its real length is greatly increased by a spiral fold of membrane, which winds along the canal from one end to the other, so as to convert it into an helical tube. And in the Sword-fish, the intestine has an evident spiral disposition, presenting seven turns before it enlarges into the wide colon which terminates it. In the class of REPTILES, again, we find the *Serpents* and most of the *Lizards* adapted for animal food; and the short and slightly convoluted form of their intestinal canal corresponds with the form of their bodies. In the *Chelonians*, on the other hand, which are mostly herbivorous, and in their conformation and habits present so much resemblance to the Mollusca, we find the digestive system assuming a form of great complexity; the stomach being widely dilated, the intestine convoluted and often more than six times the length of the trunk, the surface of the mucous coat extended by folds, and the glandular apparatus highly

developed. The digestive organs of the *Batrachia* partake of the metamorphosis which has such an extraordinary influence on other systems. In the tadpole condition, the food consists of the soft and decaying animal and vegetable matter of our ponds; which requires much elaboration to convert it to nutritive materials. The intestine is here of enormous length, with little dilatation in any part, and coiled spirally in the abdomen. After the adult form is attained, the food is mostly animal; and the whole canal becomes greatly shortened in relation to the body, scarcely any convolutions being now presented; but the separation of its parts is more evident, the stomach and colon existing as distinct dilatations.

277. The digestive organs of BIRDS will here require but little description, since they have already been so frequently alluded to. The absence of teeth prevents mastication in the mouth; and where the nature of the food requires insalivation, it is performed in the *crop* (*a*, Fig. 106), a dilatation of the œsophagus copiously furnished with secreting follicles. In the rapacious birds, however, this is absent or very little developed (*a*, Fig. 107). The second stomach, or *ventriculus succenturiatus* (*b*, Fig. 106, 107), is the one in whose parietes the *gastric* secretion appears to be formed, which is the most active in the solution of the food. This is thoroughly incorporated with it in the *gizzard*, *c*, which is a hollow muscle, furnished with a hard tendinous lining. In the graminivorous birds, it is extremely strong and thick; and pebbles are swallowed by the animal to assist mechanically in the reduction of the food. In the rapacious birds, however, no such assistance is required, the food being easy of solution; and the walls of the gizzard are thin and membranous, (although not destitute of muscular and tendinous fibres), and the three cavities are almost continuous (Fig. 107). The remainder of the intestine exhibits little variation in diameter until it approaches its outlet; but we observe in many of the graminivorous species two curious appendages in the form of cœca, opening into the tube (Fig. 106, *d*). The use of these is not known; but they are found of considerable size in many Mammalia, and in a rudimentary form in man.

278. Among the MAMMALIA we observe the highest development of the digestive organs, the different forms of which are closely connected (as has been already seen § 208) with the structure of every other part of the fabric. The mechanical division and insalivation of the food are here performed in the mouth; and many species are provided with cheek-pouches, which answer the same purpose as the crop of birds. The structure of the stomach is determined by the nature of the food; its cavity being small and almost in a line with the canal in the carnivorous species, whilst in the herbivora it is large and complex, with cœeal dilatations in which the food is delayed. In the herbivorous Cetaeca and Ruminating quadrupeds, it assumes its most peculiar form. In the

latter, the food first enters a large cavity termed the *ingluvies* or *paunch* (Fig. 110, *a*), which is analogous to the crop of birds, receiving the crude unmasticated food, and moistening it by its secretions. It is thence transmitted into the second cavity, *b*, which, from the reticulated appearance of its walls, occasioned by the irregular folding of its internal membrane, is termed the *reticulum* or *honey-comb stomach.* This cavity has an immediate communication with the œsophagus; and by two valvular folds with which the opening is provided, the aliment swallowed is directed, either into the first stomach, if it be crude and unmasticated, —into the second, if it be fluid,—or into the third, after it has been returned to the mouth. The second stomach appears the appropriate receptacle for the *fluid* which is swallowed; and it is here that the remarkable provision of water-cells is found, for which the camel has been so celebrated, but which exists, in a greater or less degree, in most Ruminantia. These cells (represented in Fig. 108) are bounded by muscular fasciculi, by the contraction of one set of which, their orifices will be closed and their contents retained, and, by the other, their fluid may be expelled. It is very interesting to trace the same arrangement presented in a rudimentary form in the stomachs of man and other animals; for on examining the disposition of their muscular coat, the fibres are found to lie in the manner shown in Fig. 109. In this second stomach, the food transmitted from the first is rolled up into balls, which are transmitted at intervals to the mouth, where they are again masticated, and completely ground down. When finally swallowed, the food is directed, by the peculiar contrivance already adverted to, into the third stomach, *c*, the *omasum*, commonly called the *many-plies*, from the peculiar manner in which its lining membrane is disposed. This presents a number of folds lying nearly close to one another like the leaves of a book, but all directed by their free edges to the centre of the tube; a narrow fold intervening between each pair of broad ones. The food has therefore to pass over a large surface before it can reach the outlet of the cavity, which leads to the *abomasum* or fourth stomach, *d*, commonly called the *reed.* This is the seat of the true digestive process, the gastric secretion being confined to it; and it is from this that the *rennet* is taken, that is employed in coagulating milk,—a power which it derives from the acid with which it is imbued. In the young animal, the milk which forms its nourishment passes directly into this stomach,—the aperture leading to the first and second being closed, and the folds of the third adhering together so as to form a narrow undivided tube. In many herbivorous animals, the intestine is of enormous extent, dilating below into large cavities with folded surfaces; and in the Sheep it is thirty times the length of the body. Approaches to this complex structure may be seen in other herbivorous orders, such as the *Pachydermata* and *Rodentia*, which have stomachs more or less completely divided internally by a partition, although this

division is not indicated externally. In the *Carnivora*, on the other hand, the stomach is small, the membrane lining the canal is not folded, the intestine not dilated below, and the whole length of the tube sometimes, as in the Felinæ, not more than three times that of the body.

279. The evolution of the apparatus for nutritive absorption having been thus traced from its simplest and most general, to its most complex and specialised form, it remains to be enquired how far the external surface retains in the highest animals, as in plants, that power which so peculiarly characterised it in the lower; and whether it has entirely surrendered the function of absorption to the vascular apparatus distributed upon the walls of the digestive cavity, or still contributes to it in a subordinate degree. It seems now well established by experiment that the latter is the case; and that in animals with a soft skin, and even in those partly covered with scales, an absorption of fluid may take place, either from water in contact with it, or from a moist atmosphere, especially when the usual amount of fluids in the body has been diminished by excessive transpiration or in other ways. Thus, Dr. S. Smith mentions that a man who had lost, during an hour and a quarter's labour in the Gas Works, 2lbs. 15oz., regained 8oz. by immersion in a warm bath at 95° for half an hour.* Although cutaneous absorption can scarcely be regarded as the regular channel for the introduction of fluid into the system, it is obviously a most important supplementary means, being capable of acting most energetically, when, from any cause, there is a diminution of the usual supplies, or an excessive expenditure.

280. To enter at length into the embryonic development of the digestive apparatus, would be incompatible with the plan of this work; but a general view of it may be given. Its simplest evolution may be seen in the gemmules of the Sponges, which at first are permeated by no canals; but, as they fix themselves, depressions are seen on their surface, which gradually deepen into tubes, and these ramify and unite to form the system of passages peculiar to these beings. Its most complex forms may be traced from an equally simple commencement; for in the embryo of the Vertebrata the intestinal canal first exists as a straight tube, formed by a fold of the germinal membrane (§ 536); thus evidently corresponding with its condition in the lower Annulose tribes. The two ends of this tube are at first closed, the middle portion opening into the yolk-bag, which contains its store of temporary nutriment. In the human fœtus, the oral opening is formed at the 6th week, the opposite one a week later; sometimes the latter remains closed even until birth. The stomach is first distinguished, by a projection of the tube towards the left side, about the 9th week; but the separation of the small and large

* For a very able and complete discussion of this subject, and for many valuable facts and experiments, the author has much pleasure in referring to the Prize Essay on Cutaneous Absorption, by his friend Dr. Madden. Edinb. 1838.

intestines is of much later occurrence. The folds of the mucous membrane, which are confined to higher animals, do not appear until a late period of gestation. The intestine gradually acquires increased length, that portion being most extended longitudinally which remains of the smallest diameter. The development of the digestive glands will be hereafter noticed (CHAP. XI).

CHAPTER VI.

CIRCULATION OF NUTRITIVE FLUID.

General Considerations.

281. In beings of the most simple organisation, whether belonging to the Animal or the Vegetable kingdom, we have seen that every part of the surface is equally capable of absorbing the fluid aliment brought in contact with it; and that the materials of the tissues are supplied by the constant permeation of the nutriment thus immediately derived from external sources. In such, therefore, it might be inferred that no transmission of fluid from one portion to another would be required for the purposes of the economy; and we find no evidence of its existence, either in a structure specially adapted to it, or in any visible motion of such fluid. As in more complex organisms, however, a small part only of the surface is particularly appropriated to the function of Absorption, it becomes evidently necessary that means should exist of conveying to distant parts the nutriment they require. This is effected by the *circulation* of the fluid taken up by the absorbents, through vessels or passages adapted to this purpose; and it may be regarded as a general statement of the condition of this *vascular* system in all classes of living beings, that *its development is proportional to the degree of limitation of the power of absorption*, by which the parts imbibing aliment are insulated from those requiring supplies. But the conveyance of nutrient fluid to the remote parts of the system is not the only object to be fulfilled by the circulating apparatus; since the crude aliment must be exposed to the influence of the air, before it becomes fit for its ultimate purpose, and that which has once passed through the tissues must undergo a similar process to restore it to its proper condition. This process, which constitutes the function of Respiration (CHAP. IX.), requires that the circulating fluid should pass through certain organs adapted for its performance; and hence the arrangement of the vascular system is modified, not only for conveying the alimentary materials from the part of the system where they are introduced to that where they are required; but also for causing it to be

brought, during some part of its transit, into retation with the atmosphere. It is very evident, therefore, that the uninterrupted performance of this function is necessary to the continuance of life; since not only does the nutrition of the tissues wholly depend upon the materials thus supplied; but the constant stimulus of the vital fluid is necessary to excite them to the performance of their appropriate actions (§ 168).

282. In the study of the Circulation, we shall have reason to see the peculiar advantage to be derived from the investigation of the simplest conditions under which it may be performed. It has been from the confinement of their attention to this function as it exists in the higher animals only, that many Physiologists have adopted incorrect and narrow views as to the powers by which it is maintained;—views which are incapable of extension to the whole animal kingdom, far less to the vegetable creation, and which must therefore be fundamentally erroneous. We shall endeavour to show that principles of higher comprehensiveness may be attained, by embodying the principal facts relative to the circulation of nutrient fluid, through all the classes of living beings in which it presents itself.

Circulation in Vegetables.

283. The tissues of the lower tribes of CRYPTOGAMIA, being almost entirely *cellular* in their structure, do not seem to be adapted for any very regular or definite transmission of fluid. It has been already stated (§ 246) that the ALGÆ absorb by their whole surface; and there appears to be so little communication between different parts of the same individual, that if one portion be suspended out of the water, it will dry up and die, whilst that which remains immersed will preserve its freshness. No trace of vessels is discoverable in this order; the cells present a rounded form in almost every part; and the only deviation from this arrangement occurs in the *veins* which strengthen the foliaceous expansions of some species, where we find the cells somewhat elongated and presenting an approach in form to woody fibre. Amongst the LICHENS a similar uniformity of structure prevails; no appearance of vessels is perceptible; but wherever the form of a stem is assumed, the cells, which are rounded in the foliacious expansions, possess more or less elongation. From the circumstance already mentioned—that in this tribe the power of absorption is usually restricted to the side least exposed to light—more capability of diffusing the nutrient fluid is required; and it appears that when the absorbent surface is placed in water, the liquid is transmitted in the course of the elongated cells, to the whole plant. In the FUNGI we may trace a further development of this simple form of the Circulating apparatus. In the higher species, such as the Mushroom tribe, the nutriment which is entirely received by the radical fibres at its base, is transmitted by the elongated cells of the stem, and probably

through certain hollows left by the separation of the tissue (termed *intercellular spaces)*, to the expansion on its summit, where it is diffused in every direction. It may be regarded as a general expression of the structure of these cellular plants, therefore, that when there is no tendency to prolongation in a particular direction, the vesicles retain their rounded form, and transmit fluid with equal readiness towards all sides; but that when any separation of the different parts takes place, by the restriction of the function of Absorption to one portion of the surface, there is a tendency to the evolution of a stem formed of prolonged cells, in the direction of which the fluid is conveyed most readily to the other parts of the system.

284. In the higher group of Cellular plants, consisting of the MOSSES and FERNS with their allies, we find a much more evident approach to the vascular structure and the general circulation of the Phanerogamia. Still, however, its lower tribes (such as the Hepaticæ § 61) are so closely connected with the more perfect forms of the preceding group, that what has been said of them will be equally applicable to these. Among the MOSSES strictly so called, however, we find several species in which a complete stem is developed, furnished with radical fibres at its base, and bearing a number of veined leaves regularly arranged upon it. In these the cellular tissue of the stem and of the veins of the leaves becomes considerably elongated, so as almost to resemble woody and vascular structure; and there can be no doubt that the circulation of the fluid absorbed by the roots is actively performed by this channel, especially as late observations have shown that there is on the Mosses a special *exhalent* apparatus for the transpiration of fluid (§ 429), like that which will be described as existing in the more perfect plants.* In the FERNS the evolution of a true woody stem proceeds to a much greater extent; and in it is found a vascular structure scarcely differing from that of the Phanerogamia. Although little has been observed as to the circulation of sap in this order of plants, it can scarcely be doubted that the fluid absorbed by the roots ascends, through the fibro-vascular tissue of the stem, to the leaves, as in flowering plants; since we find vessels of precisely the same character with those which are known to be the peculiar channels of this fluid, namely, the dotted and reticulated ducts (§ 24, 29).

285. We shall therefore pass on at once to describe the circulation in the PHANEROGAMIA where it has been more fully investigated. Each annual layer that composes the wood of the stem of EXOGENS (§ 51), consists

* The *Characeæ* (§ 62) being usually regarded as allied to the Mosses, this might be supposed to be the proper place for noticing the curious circulation which has been observed in the Chara, Nitella, &c.; but this circulation cannot be placed upon the rank of that which we are now considering, not being *general*, but confined to single cells, and evidently connected with their *individual* nutrition. It will, therefore, be described, along with analogous phenomena observed in single cells of the Cryptogamia and of flowering plants, in Chap. VIII. on Nutrition (§ 353).

of dotted ducts and woody fibre, intermixed with more or less of cellular tissue; the vessels being usually situated at the inner part of the ring, and the fibrous tissue, which is not formed until later in the year, lying externally to them. The vessels have the greatest diameter in long slender stems, and in plants of active vegetation, where the sap has to be conveyed with rapidity to a considerable distance, as in the vine; and they are usually larger, also, where the stem is dense,—as in the oak, elm, mahogany, &c.,—than where its softness and laxity of texture allow it to convey fluid more readily,—as in the pine tribe, which is destitute of any distinct sap-vessels, or in the herbaceous plants, where they are usually small in proportion. The deposition of the products of secretion, which gives strength and firmness to the *duramen* (§ 51), destroys or greatly diminishes its power of transmitting fluid; and it is consequently through the external layers only, which constitute the *alburnum* or sap-wood, that the nutritious juices ascend. The *bark* consists, like the wood, of fibro-vascular mixed with cellular tissue; but the latter greatly predominates; and there are, moreover, a much larger number of *intercellular* spaces or *passages* than exist in the interior of the stem. The foot-stalk of each leaf is connected with the wood and bark; the upper stratum of vessels communicating with the former, the inferior one terminating in the latter. These two strata appear to remain distinct throughout the expansion of the leaf; and there is a remarkable and important difference in their functions.

286. The course taken by the sap is the following. The fluid absorbed by the roots is conveyed upwards, through the stem, by the woody fibre and ducts of the alburnum, to the upper surface of the leaf. Hitherto the *crude sap* (as it is termed) is quite unfit for the nutrition of the system; and the processes which it undergoes in the leaves are necessary to render it capable of its destined function. These processes consist of the exhalation of much of the watery portion (CHAP. X.); and of an interchange of gaseous ingredients with the atmosphere (CHAP. IX.), by which a large quantity of carbon is added. It is found as their result, that the fluid which is transmitted along the inferior stratum of vessels to the bark, contains the peculiar secretions of the plant, and is adapted to supply the demands of its nutritive functions. This fluid, now termed *elaborated sap*, or proper juice, descends through the cellular tissue and intercellular passages of the bark, furnishing the materials of the new layers which are being added to the alburnum and *liber* (or inner bark); and a portion of it is carried to the interior of the stem by means of the medullary rays (§ 23, 51), the cells of which, being elongated horizontally, are adapted to convey fluid in that direction. Very little of the elaborated sap reaches the roots, from which the motion commenced; and none of it, except that small quantity which mixes with the ascending current (§ 252), is again

transmitted through the system; hence this circulation is not exactly parallel to that of the higher animals, though obviously analogous to it.

287. Of the precise course of the sap in ENDOGENS, we have no certain knowledge; there can be little doubt, however, that it ascends through the ducts (which are usually large, especially in long, firm, slender stems, as those of the cane, &c.), and the woody fibre; and that after ramifying through the leaves, it descends along the cellular portion of the stem.

288. It is probably to the motion of the elaborated sap in the intercellular spaces, that the observations of Schultz and others apply; although the existence of a distinct set of "vital vessels" has been alleged. This curious circulation was first observed in plants with milky juices, and was thought to be peculiar to them; but this error was probably caused only by the fact, that the globules contained in these juices rendered their motion more perceptible; since later observations have proved its existence in plants whose fluids are transparent. The channels in which it takes place are not straight tubes like the ducts in which the sap ascends, but are of irregular shape, and inosculate freely with one another like the *capillaries* of animals (§ 297, Fig. 134); and if the statements of Schultz are to be relied upon, the movement of the nutritious fluid is exactly of a corresponding character in the two cases.

289. The cause of the ascent of the sap in the stem has long been a disputed question amongst physiologists; some attributing it altogether to mechanical influences, and some regarding it as a purely vital (and therefore completely inexplicable) phenomenon. A very simple experiment will show that two sets of causes must be in constant operation. If the top of a young tree be cut off in the spring, and the divided extremity be immersed in water, it will absorb sufficient quantity of fluid for the temporary supply of the leaves; whilst, on the other hand, the portion of the stem left in the ground will continue to pour out the fluid drawn up by the roots. It is then evident that the propulsive power of the roots, for which we have already endeavoured to account (§ 252), is a partial but not the entire cause of the ascent of the sap in the stem; since the latter will continue by simple imbibition, when the open extremities of the vessels are placed in fluid, provided that the functions of the leaves are sufficiently active to occasion a demand for it. Moreover, there would seem no reason why the spongioles should not be as capable of absorbing fluid in the winter as in summer; and if the ascent of the sap depended entirely upon them, we should expect that it would be continued. That they are thus capable has been frequently shown, by grafting a shoot of an evergreen upon a stock whose leaves are deciduous; and it is found that the uninterrupted continuance of the demand meets with a corresponding supply. A still more striking experiment is to train a shoot of an outdoor vine, or other plant, into a hothouse during the winter; the unusual

stimulus will cause an immediate development of the buds, for which a supply of nutriment is required; and this is derived from the roots, whose usual torpidity at this season is thus remarkably interrupted. Careful examination of the first movement of the sap in spring, also leads to the same result; for it is now ascertained that the upward flow begins near the buds, and that it may be progressively observed in the branches, trunk, and roots, —the latter not commencing their action until the superincumbent column has been removed. It can scarcely, then, admit of a doubt that the demand for fluid, occasioned by the vital processes which take place in the leaves, is the essential cause of the motion of the sap in the higher parts of the tree; and that the propulsive power of the roots is principally expended in raising it to the sphere of that influence. It is evident that the quantity of fluid absorbed by the roots will be proportioned to the rapidity of its removal by the leaves above; just as the continued rise of oil in the wick by simple capillary attraction is regulated by the combustion at its apex.

290. To whatever extent we regard the propulsive power of the roots as influencing the rise of the sap to the leaves, it is obvious that it can have no effect whatever upon the descending current. The course of the latter motion cannot be distinctly ascertained. It has been supposed that it is partly due to the influence of gravity; but though the movement may be affected by it, in the same manner with the circulation of animals, we cannot regard it as dependent upon this agent, since it takes place in branches which ascend towards the stem, and continues proceeding towards the root when the upper part of the stem has been so bent that its direction is really upwards. Moreover, it has been shown that it is assisted by the vibrations of the stem, which are produced by the wind; and this may be conceived to have the same kind of influence over it as muscular action has on the capillary circulation of animals. It is quite certain that it is independent of any contraction of vessels, and that it is closely connected with the activity of the nutritive processes. If the description given by Schultz, and confirmed by other observers, of the motion of fluid witnessed by them, really applies to this general circulation of nutritious or elaborated sap, it obviously bears a very close analogy with the movement of the blood in the capillary vessels of animals; since this also would seem less dependent upon the *vis a tergo* or impulsive force of the heart, than upon the new set of attractions and repulsions created between the particles of the fluid and the surrounding tissues, by that mutual action in which the process of nutrition consists. This *vital circulation*, as it has been termed, may be seen not only in detached parts, in which it continues for some time, but also in the growing plant. The currents traverse the principal passages in different directions, and pass through the lateral connecting tubes, with considerable rapidity. The motion occasionally stops suddenly, and then recommences; it is checked by cold and renewed by

warmth; but it is irrecoverably destroyed by a strong electric shock. The *Ficus elastica*, *Chelidonium majus* (Celandine), and *Alisma plantago* (water plantain), are the species in which it has been most studied.

291. The *development* of the circulating system during the growth of vascular plants, has not yet been made an object of special attention; the general facts with which we are acquainted, however, correspond exactly with the principles which have been previously stated. As the absorption of nutriment by the embryo within the ovule (§ 255) appears to take place through the whole surface, there is no transmission of fluid from one portion to another; nor do we find, even at the period of the ripening of the seed, any distinct vascular structure. As far as its circulating system is concerned, therefore, the young plant at the commencement of germination is on a level with the simplest cellular tribes. During the rapid longitudinal development, however, which then takes place in the stem and root, there is of course a peculiar transmission of fluids in those directions; and this appears to be at first performed, as in the stem of the Fungi, by elongated cells and intercellular passages. It is not until the true leaves are expanded, that we find a distinct formation of woody or vascular structure; and it is very interesting to remark that the ducts of young plants often present the appearance which is characteristic of the Ferns, having the spiral fibre more or less regularly disposed within them (Figs. 15, 17); whilst after the stem has ceased to increase rapidly in length, these canals are converted into dotted ducts (Fig. 18) by the process already described.

Circulation in Animals.

292. In tracing the evolution of the circulating system through the animal scale, it will be easy to discover its conformity to the same laws as have been shown to govern its development in the vegetable kingdom. In proportion as the power of absorbing aliment is restricted to one part of the surface, whether external or internal, does it become necessary that means should be provided for conveying the nutritious fluid to distant organs, not merely that it may furnish the supplies which they are constantly requiring for the maintenance of their respective structures and the manifestation of their vital properties, but also that it may itself undergo certain changes which are essential to the continuance of its characteristic qualities. Not only does the circulation of fluid through the system enable the new materials to be deposited in their appropriate situations, but it also takes up and removes the particles which, having manifested a tendency to disorganisation, are no longer fit for the offices which they previously contributed to perform; and by the various processes of secretion these are separated from the general mass, and either appropriated to some other purpose in the economy, or altogether carried out of the structure. The excretion of carbon by the respiratory apparatus is one of the most considerable and important of these processes; and it

will be found that the distribution of the circulating apparatus has always an express relation to the conditions under which it is performed. In fact, so peculiar is this adaptation in the higher animals, that many have considered the vascular system under two heads,—that belonging to the *general* circulation of nutritious fluid through the system,—and that which performs the *respiratory* circulation, conveying the blood, which has been rendered impure by the changes it has previously undergone, to the organs where its physical and vital properties are to be renewed by contact with the air. Respiration differs not in *kind*, however, from the other functions of excretion, but only in its relative importance; and though in air-breathing animals, whose nervous energy and locomotive functions can only be maintained in full vigour by a constant supply of warm arterial blood, its cessation even for a short time is fatal, there are many amongst the lower classes in which it can be suspended for a considerable period with impunity, and in which the increased amount of other secretions appears to counterbalance the diminution in its products. We find too, even in the highest Vertebrata, peculiar modifications of the circulating apparatus for the performance of other secretions, as that of the liver in Mammalia, and that of the kidneys in Birds: so that it should rather be stated as a general fact that, in proportion to the variety of the organs, and of the functions they perform, is the complexity of the circulating apparatus which supplies them,—than that it undergoes modification according to the conditions of the respiratory system alone, as Cuvier maintained. In proportion as the function of absorption is restricted to one part of the surface, that of respiration will be limited to another; and the processes of nutrition, and the formation of secretions will go on in parts of the structure distant from both; and all these must be brought into harmony by vascular communication, the arrangement of which will evidently vary from the most simple to the most complicated form, according to the number and variety of the offices to which it is subservient.

293. The movement of fluid which takes place through the ramified canals of the PORIFERA, can scarcely be regarded in the light of a general circulation; since, as already stated (§ 265), these canals appear but an extension of the absorbent surface, adapted to bring every part of the soft gelatinous tissue into contact with the fluid which supplies its aliment; and the motion of the fluid through them must be regarded as analogous to the passage of food through the alimentary canal of higher animals.*

* This is not the only analogy presented by it, however; for all the nutritive functions are so completely blended together in these beings, that the same process may be regarded as combining within itself several which are distinct in higher animals. It will hereafter be shown that where a distinct vascular system is evolved in this kingdom, its primary object is to convey the nutriment that has been absorbed, into the minute ramifications or *capillaries*, in which alone it comes into relation with the tissues it supports; so that the very walls of the trunks which convey it, are furnished with a distinct set of branches (the *vasa vasorum*), for

The circulation which has been described in the stems and fleshy masses of some POLYPIFERA, appears to have a similar character, their canals being analogous to those of the Sponge, but furnished with polypes at their entrance (§ 116 *note*, 119); it seems dependent on the activity of the nutrient processes of the parts towards which it is directed, and equally uninfluenced by any mechanical propulsive force. In the bodies of the polypes themselves, no more general circulation has been observed than that already stated (§ 266). In some of the INFUSORIA, it is affirmed by Ehrenberg that a distinct set of reticulated vessels may be seen, channeled out beneath the surface, in which a movement of fluid may be perceived, independent of any impulsion, and apparently similar to the circulation of the elaborated sap in the intercellular passages of plants; but it may be doubted whether the appearance is not rather due to a prolongation of the digestive canals, in which similar motions have been observed; since it has been especially noticed within the Volvox and other large compound animalcules in which the alimentary fluid appears to be conveyed by its means to the contained embryos. In the lower ENTOZOA no other movement of fluids seems to take place than that which exists within the digestive canals; these simple beings being endowed with the power of absorption by every part of their surface, as well as by the channels excavated in their interior.

294. Among the true RADIATA, however, as well as among the higher *Entozoa* which have been associated with the Articulated classes, a true circulation unquestionably exists; but it presents itself in a very simple form, which bears as close a resemblance to that which exists in plants as to that exhibited in the higher animals. No heart, or other organ of impulsion is yet developed, but the vessels which absorb the nutritive portion of the food received into the digestive cavity, convey it to distant parts of the system, without any apparent cause for its continued movement. Although some have argued for the presence of a circulating apparatus in the ACALEPHÆ, it seems scarcely correct to regard the prolongations of their digestive cavity in that light; since we universally find that the true circulating system conveys, not the crude fluid which is the first product of digestion, but a more highly elaborated material fit to be applied at once to the purposes of nutrition. The want of any separate vascular system has necessitated in this class a most curious and complicated ramification of the digestive canals (§ 269); and in these a distinct motion of fluid has been perceived, which, nevertheless, can be scarcely

their own nourishment. Now in the Sponge, the surface which absorbs, and that on which the nutritive changes take place, appear to be identical; so that the motion of fluid over them seems to combine the character above mentioned with that of the capillary circulation. To the latter, indeed, it appears to have much resemblance in the forces by which it is maintained; since no ciliary motions or impulsive contractions can be detected in this class; and the new set of attractions and repulsions created by the nutritive processes constitute the only force whose operation can be suspected (§ 318).

regarded as a true circulation. In the *Beroe*, however, several observers agree in describing a separate vascular system, which absorbs fluid from the sides of the digestive canals, and carries it to the ciliated processes for aeration, its movement being made apparent by the globules which it contains. A more distinct vascular system is found in a very curious species of this group, the *Cestum Veneris* (girdle of Venus), a riband-like animal which sometimes attains the length of 5 or 6 feet. The alimentary canal, which is short and straight like that of the Beroe (§ 269), runs *across* the centre of the body; but a system of vessels encircles its outlet, which sends branches through its whole length, and particularly along the ciliated margins, where the aeration of the nutritious fluid appears chiefly to take place. This conformation presents a remarkable contrast to that which has been just described in other species, and illustrates the general principle laid down in § 281.

295. Among the ECHINODERMATA we find a gradual restriction of the digestive cavity to the central portion of the structure, and an increased evolution of the vascular system. Thus, in the *Asterias*, the stomach is prolonged into the rays, and we do not meet with a circulating system as highly developed as in the *Echinus*, where the alimentary canal runs through the centre of the body alone. In the former animal, a vessel is found lying on the surface of each digestive tube and receiving minute branches from its cœca; having proceeded from the rays to the centre, they unite with other branches from the stomach to form a circle or vascular ring round the upper part of the body. This is connected with a similar ring surrounding the mouth on the lower surface, by means of a vertical descending vessel, which Tiedemann found to possess muscular irritability, and regards as a simple form of heart; whilst from the lower ring, proceed other vessels which are distributed through the body. The vessels first mentioned probably act as absorbent veins, and convey the nutritious fluid to the central receptacle, whence it is propelled through the second set of vessels, which may be regarded as arterial trunks, to the system at large. No communication has yet, however, been detected between the terminations of the second set of vessels and the commencement of the first, such as would be necessary for a continued circulation; and the supposed course of the vital fluid has not been verified by observation, being merely conjectured from the distribution of the vessels. In the *Echinus*, the vessels which arise from the sides of the alimentary canal unite into a trunk (apparently analogous to the mesenteric vein of higher animals); this, however, does not immediately convey the absorbed fluid to the system at large, but subdivides again into minute branches that ramify over the peritoneum (the serous membrane lining the cavity that contains the viscera § 36), to which water is admitted for the purpose of aerating the blood. Here, therefore, we find an express modification of the circulating apparatus for the purpose of carrying into

effect the second of its principal objects; and it is interesting to trace this modification so low down in the scale, before a heart is distinctly evolved, and whilst the motion of fluid in the vessels seems dependent upon the changes which it undergoes in them. After ramifying on the membrane which lines the shell, and being submitted to the respiratory process, the circulating fluid passes through a series of vessels which convey it to a ring formed round the outlet of the alimentary canal; and from this it enters a tube which traverses directly to the opposite extremity of the intestine, where a short oval canal is situated, which, possessing muscular parietes, and exhibiting during life slow but distinct contractions, is regarded as a heart. From this pass out arterial trunks which convey the blood to the muscles and dental apparatus, and along the course of the intestine; in its passage into the veins first described, it probably derives from the intestine the nutriment there prepared, and thus the circle is completed; the same simple arrangement serving for the absorption of the chyle or nutritious fluid, its mixture with the blood which had previously circulated through the system, the aeration of the mixed fluid by being brought into relation with the water introduced into the cavity of the shell, its return to the organ which serves as a heart, and its distribution to the general structure for the purposes of nutrition, secretion, &c.

296. In the *Holothuria*, as already stated (§ 107), a transition may be perceived from the Radiated to the Annulose form; and it is curious to observe how all its systems are modified in accordance with this variation from the regular type of the Echinodermata. Instead of a distinct contractile cavity, as in the Echinus, we find a long pulsating vessel or artery accompanying the intestine, which resembles that of the Articulata in general; the blood that is propelled into its minute ramifications, seems, in its passage into the corresponding veins, to absorb the nutritious matter from the intestinal surface, as in the Echinus; these veins again unite in one large trunk, from which the blood proceeds to the respiratory apparatus. The latter, however, differs from that of the Echinus in being formed more upon the plan of that of Insects; the water introduced from without ramifying through a system of tubes, on the sides of which the vessels conveying the blood are distributed. After having been aerated by these means, the circulating fluid is conveyed by a trunk, into which the respiratory capillaries again unite, to the pulsating vessel from which it was first propelled. It is scarcely possible to conceive that the impulsion which it there receives can be sufficiently strong to convey it through all the complex ramifications that have been described, and through a double system of capillary tubes, back to the centre from which it was originally distributed; especially since the pulsations which have been witnessed in the central cavities are slow and feeble. That the passage of the blood through the respiratory apparatus is independent of it there

seems good reason to believe; and the very complete analogy which exists between this circulation and that of the higher plants affords a striking confirmation of this view. As in plants, the nutriment taken up by the absorbent vessels enters at once into the general circulating system, by which it is conveyed to the respiratory organs; and after leaving these, it traverses the fabric by a set of vessels in which the nutritive changes appear to be performed. We have seen that in plants, the motion of the fluid in these canals appears to be entirely independent, not only of the propulsion of the roots, but of every direct mechanical impetus; and there seems no difficulty, but, on the contrary, the highest probability (if consistent with other facts as it will hereafter appear to be), in supposing that the same causes, whatever may be their nature, are in operation in this instance also.

297. The Articulated classes are usually regarded as inferior to the Mollusca in the evolution of their circulating apparatus; and it certainly never manifests itself in the same highly-developed form in them, as in the last-named group. It has long been acknowledged, however, that it is a great error to suppose that Insects have no circulation, as it was formerly imagined; and perhaps the supposed inferiority of their vascular system is more apparent than real. The question is not so much as to the rapidity with which the blood moves through the vessels, as with regard to the amount of that fluid brought into contact with the tissues after being vivified by exposure to the air. From the peculiar construction of the bodies of Insects (the respiratory tubes being carried into every part of them) the process of aeration is universal, instead of being limited to a particular part; and hence a much less rapid exchange of the circulating fluid answers the same end. Again, it will appear that the movement of the fluid in the vessels is much less connected with the muscular contraction of a central organ of impulsion, than in the Mollusca,—most of the classes of which have a powerful heart, whilst in Insects and the Vermiform tribes there is nothing but a pulsating vessel: but this would seem not improbably due to the energy of the nutrient processes in the capillary system of the Articulata, whose active habits cause them to require a much more continual supply than the slow-moving Mollusca. It is only in the *capillary* vessels, that is to say, the minute ramifications which unite the arteries conveying blood *from* the heart, with the *veins* returning it *to* that organ, that the blood acts upon the tissues of the body; the larger trunks serving only to distribute it to them. In Vegetables, the circulation of elaborated sap may be regarded as entirely capillary (§ 288), the fluid moving through its anastomosing channels just as through the web of a frog's foot; but in proportion to the number and variety of the processes going on in different parts of the system, does it become necessary that they should be harmonised with one another and put under a common control. In the higher animals, therefore, we perceive that the

action of the heart is evidently the chief means of the circulation of the blood; but still there is abundant evidence to prove that the rapidity and force of its motion through any particular organ, and the quantity which is transmitted to it, are greatly modified by the activity of the changes to which it is there conducive (§ 318). In the Insect tribes, therefore, it is scarcely improbable that the energy with which the nutrition of the individual organs is carried on, has a considerable influence in keeping up the afflux of blood to them, and in thus producing its general circulation; although the mechanical agents provided for its maintenance would be, as far as can be ascertained, of themselves insufficient for the active propulpulsion of fluid, or at any rate much less powerful than those of the Mollusca.

298. Among the higher ENTOZOA, a circulating system may be detected, not very dissimilar in character from that which exists in the Asterias. The intestinal canal itself ramifies extensively through the body, and hence a very active movement of fluid in separate vessels is not required. Thus, in the curious *Diplozoon* (§ 272), a set of vessels is seen ramifying from two principal trunks, which traverse opposite sides of the body, and along these the blood moves in opposite directions (Fig. 111). In the *Planaria*, again, notwithstanding the complex ramification of the alimentary canal, we find a regular vascular system consisting of one central and two lateral trunks, which are united by very numerous anastomosing branches (Fig. 112). The larger parts sf the longitudinal vessels have been observed to contract and dilate; but neither a regular progressive circulation, nor the transmission of the blood to any special respiratory organs, has yet been observed. In tracing the circulating system through the Articulated classes, a remarkable conformity to this general type will be perceived; for the tendency to symmetrical development has affected even the vascular system, so that the dorsal vessel, disposed along the centre of the back, propels towards one extremity the blood returned to it by venous trunks running in the contrary direction. A characteristic illustration of this type is shown in the vascular system of the *Erpobdella*, one of the ANNELIDA allied to the Leech; in Fig. 113, are seen the dorsal vessel conveying the blood forward, and the two lateral veins in which it moves towards the posterior part of the body. Various modifications are engrafted upon this simple plan, in conformity with the distribution of the respiratory organs, of which the form and situation differ so remarkably throughout the class. Thus, in the Leech, a set of branches are sent off from the lateral vessels, and ramify minutely upon the sides of the pulmonary sacs into which the air is admitted for the aeration of the blood (§ 392); and in those species which have the gills situated along the whole length of the body, the distribution of the vessels is similar. There are some, however, as the Sand-worm, which have the gills situated on the head only; and in these the blood is directly propelled to them by the

dorsal vessel, and returns to the veins; part of it passing to the system, and part to the branchial apparatus, at each contraction.

299. From the redness of the blood of many of the worms, and the transparency of their bodies, the movement of the fluid may be very distinctly seen in them. The progressive contraction of the dorsal vessel from before backwards, greatly resembles the peristaltic motion of the intestinal canal. One of the most curious modifications of the vascular system presented by the Annelida is that which exists in the common *Earth-worm.* There is here a dorsal vessel, which is not simple as in other cases, but gives off large loops that seem to have a high degree of contractile power (Fig. 114); for in the motion of the blood forwards (the waves of which can be distinctly seen, if the animal be kept without food for a time, until it has discharged the black earth which usually fills the intestinal canal,) these lateral arches appear to perform a considerable part. The blood is conveyed backwards by a vessel situated along the abdominal surface, from which are given off the branches that ramify on the respiratory sacs. In some of the animals belonging to this class the motion of the blood does not seem to be regular or definite, but to have an undulatory uncertain character; whilst in the higher species it is very constant, and is a spectacle of great beauty. There is still, however, a deficiency of concentration in the apparatus; the long pulsating vessel having but very feeble power compared with that of the dense muscular heart of some of the higher classes. In the MYRIAPODA, the condition of the circulating system is nearly the same, the contractile dorsal vessel extending from the tail almost to the head, and there separating into trunks which, after ramifying through the system, conduct their contents again to the posterior extremity of the pulsating tube, having undergone the process of aeration in their course.

300. In the Larva state of INSECTS, the vascular system presents us with the form which exists in the Annelida and Myriapoda. The dorsal vessel runs along a considerable part of the length of the body, and, subdividing towards the head, distributes its contents to the channels which convey it backwards. The blood of Insects is not, however, red like that of the Annelida, but transparent and almost colourless, containing globules which have a slightly brownish tinge. Hence its movement is not easily observed, especially in parts which are not very transparent. The general plan of the circulation, even in perfect Insects, is not dissimilar from that which is exhibited in the vermiform tribes; for any special modification of it for the function of respiration is rendered unnecessary by the peculiar structure of the tracheal system (§ 394) which aerates the blood in every part of the body; and all that is necessary, therefore, is to secure a continued flow of fluid through the canals. It is during the period a little anterior to the final change, that the circulation may be observed to the greatest advantage; not only on account of the transparency and

delicacy of the parts, and the general activity of the nutritive processes, but because after the perfect Insect has emerged, no movement of fluid can be detected (except in a few instances) in the wings, which from that time seem cut off from its current. The blood which flows forwards through the dorsal vessel, after receiving its impulse by the contraction of its cavities, passes towards the head along a vessel of thinner coats which may be regarded as analogous to the *aorta* of higher animals; and this subdivides in the head into numerous branches, which are distributed to the antennæ and other parts of it, and afterwards reunite and converge into two great lateral vessels; these lie nearer the lower or ventral surface, and convey the blood towards the posterior extremity of the body. In their course backwards, they send currents to the legs and wings, which, after traversing them, return again to the main stream; it is very remarkable, however, that these currents do not appear to move in distinct vessels, as they do even among the lower Annelida, but seem to pass through different parts of the loose cellular tissue of the body in no definite tracts. In many aquatic larvæ, especially of the order *Neuroptera* (§ 89 *note)*, there are leaf-like appendages affixed to the tail, in which the circulation may be distinctly seen, the streams passing off in loops from the main trunks, and joining them again, so as to be conducted to the posterior part of the dorsal vessel.

301. The degree in which the movement of fluid takes place in the perfect Insect, depends upon the duration of its life and the activity of its nutritive functions. In the *Neuroptera*, the existence of the insect after its last change is usually brief; it does not increase in size, and either takes very little food or lives in perfect abstinence. Previously to the metamorphosis, the currents may be observed to cease in all the prolongations of the body which have, during the aquatic state, served the purpose of gills,—whether the laminated appendages that pass under that name, or the rudiments of the wings which are subsequently to be expanded in the air; and they are also withdrawn from the limbs, continuing only in the trunk. But there are many insects in which the growth of the body, combined with general activity of the nutritive functions, continues for some time after the final change; and in these, the circulation may be observed to persist, not only in the trunk but in the wings, as in the common house-fly; which, if examined sufficiently soon after its emersion, exhibits this phenomenon with great beauty and distinctness. The currents gradually disappear from the wings, however, even in these; and that no reparative power exists in them is well known, since old bees may always be distinguished from young ones by the chipped indented edges of these organs,—the result of accidental injuries which, after the circulation has ceased, can no more be repaired than similar losses of the substance of horns, nails, or other extra-vascular parts of higher animals. The chief peculiarity of the circulating system

in Insects consists in the structure of the dorsal vessel. This is no longer a simple tube, propelling its contents from one extremity to the other by the progressive contraction of its walls, but a complicated piece of apparatus composed of several distinct parts. In the larva condition it does not present externally any very striking difference from the dorsal vessel of the higher Annelida, being prolonged through the body with but little alteration in its diameter; the anterior part of it, however, is found to be a simple tube, while the posterior two-thirds are divided by valvular partitions into eight segments, corresponding with those of the body; the valves are formed by a reduplication of the inner membrane (Fig. 115), and are so adapted to each other as to allow of the passage of fluid forwards, but not of its return. In its progress towards the perfect state, the length of the dorsal vessel diminishes, whilst its difference from the arterial prolongation becomes more evident, its coats being thickened and the chambers becoming shorter and wider, and thus exhibiting an evident tendency to that concentration which we find in succeeding classes. It is interesting to perceive even in Insects a disposition to that independence of the segments which is characteristic of the inferior Articulata. The eight partitions of the dorsal vessel may be regarded as so many distinct hearts belonging to the segments in which they are respectively placed; for besides the principal current which is transmitted from behind forwards by their successive contraction, others may be seen to enter laterally from vessels which are sent to each chamber by the segment in which it is placed.

302. In the ARACHNIDA there is a still further concentration of the propulsive force, whilst the general type of the sanguiferous system is the same. The *Scorpion* has an elongated dorsal vessel, resembling that of insects, but divided into five partitions only, and possessed of firmer parieties; besides the principal arterial trunk in which it terminates, it gives off many smaller branches in its course. In the division of the class in which the respiration is performed, as in Insects, by *tracheæ* ramifying through the body (§ 402), the vessels are distributed on the same general plan; but where, as in the Spider tribe, the respiratory apparatus is more concentrated, it is evident that the vascular system must be adapted to a more active circulation, in order to maintain the same amount of energy in the nutritive operations. Accordingly we find the dorsal vessel shorter, wider, and more muscular,—presenting an evident approach, therefore, to the usual form of the heart; it gives off several branches in its course, which are distributed to different organs; and two large trunks open into it, the branches of which ramify upon the respiratory surface. From an examination of the anatomical structure of the circulating apparatus, M. Audouin concludes that the blood is first transmitted from the dorsal vessel to the system in general; that, returning from it, the fluid, now become impure, traverses the respiratory organs;

and that, after being there aerated and revivified, it returns to the dorsal vessel by the two trunks just mentioned. As no distinct channels can be detected, however, for its conveyance from the remote parts of the system to the respiratory organs, it would not seem improbable that only a part of what has been transmitted through the general circulation is conveyed to the latter.

303. It is among the CRUSTACEA, however, that we find the sanguiferous system presenting the most developed form which exists among the Articulated classes. Whilst in the lower orders, the segments of whose bodies are nearly alike throughout, the dorsal vessel is elongated and common to nearly the whole extent of the trunk, giving off branches to each segment,—in the more elevated forms we find it contracted into a short fleshy sac possessed of considerable muscular power, and concentrating in itself the propellent force which was previously diffused through the whole extent of the arterial tube. The blood is propelled by the contractions of this sac through a vascular system distributed to every part of the body; it does not appear to return, however, by distinct tubes, but rather by channels or vacuities in the tissues. By these it is transmitted, not back again to the heart, but to the *venous sinuses* as they are termed, which are simply dilatations at the commencement of the vessels that ramify through the gills, for the purpose of collecting the blood which is to be transmitted to their surface. Each *branchial arch*, or fringe of gills, has one of these vessels running along the base of its filaments, and sending a twig to every one (Fig. 116), whilst another vessel receives the blood which has in these filaments been brought into relation with the surrounding element, and which, having thus undergone purification, is fit to be restored by the general circulation. The mode in which these branchial vessels convey the blood into the cavity of the heart has not been distinctly ascertained; but there can be no doubt that it is very direct, since the circulation takes place in these animals with considerable energy. Although the influence of the power of the heart may propel the blood through the capillaries of the system, it is impossible to believe that has any control over the branchial circulation, the blood not being conveyed to these organs by distinct tubes, but meandering through the tissues; unless, therefore, the venous sinuses situated at the commencement of the vascular system of the gills have any contractile power, which no one has attempted to prove, the motion of the blood through the remainder of its course must be due to some independent agent.

304. We have now traced the Vascular system through the principal forms which the Articulated classes present to us; and when we follow a similar course with regard to the MOLLUSCA, it will be seen that even in the lowest of its classes, the central organ is as powerful, and circulation as energetic, as in the highest of the Crustacea. The diminished neces-

sity for a general circulation in the Articulata has already been shown to proceed in part from the universal permeation of air through the body; but it also results from the mechanical conditions of the system, the constant movements of the solid parts of which affect the contained fluids also.* Wherever we have hitherto traced an organ of propulsion materially affecting the current of the circulation, it has been perceived to influence it by alternate contractions and dilatations; the current which is flowing towards it being of course checked at the time when its contents are being propelled along the efferent tubes. In the Crustacea it has been shown that the cavity is simple; whilst in Insects it is divided by valvular partitions into chambers; still each one of these is but a repetition of the others, both in structure and function. This cavity may be designated, with reference to its analogue in higher forms of the vascular apparatus, the *systemic ventricle;* in contra-distinction to the *pulmonary* ventricle, which in warm-blooded animals, propels the blood through the lungs, and to the auricles, which are *receiving* instead of propelling cavities. In the Mollusca in general we find an *auricle*, or cavity adapted to receive the blood transmitted to the heart, superadded to the ventricle; and the existence of these two cavities constitutes the typical character of the heart throughout the whole sub-kingdom, although many variations are presented in their form and situation.

305. In the TUNICATA we find the heart usually composed of a thin lengthened ventricle with a minute auricle, both of these cavities appearing as dilatations of the principal trunk of the vascular system, which is distributed somewhat upon the plan of that of the Echinodermata. Thus, in the *Ascidia* the branchial folds are situated on the interior of the sac of the mantle (§ 391), and the blood which has ramified through them is returned to the heart, thence to be distributed to the system. Whilst in the Articulata the main trunk of the arterial system usually passes first to the *head*, in these Mollusca it is transmitted at once in the direction of the

* To use the language of Dr. Grant, "It is the restless activity of the worm and of the Insect that makes every fibre of their body as it were a heart to propel their blood and circulate their fluids. They require no complicated apparatus to accelerate the ever-active current of their blood, and hence the imperfect development of the great centre of their vascular system. Indeed it has been shown by Ehrenberg and by Nordnann that in the simplest of these animals, the trematoid entozoa, the blood flows through the system by the mere motions of the body, without the least motion or impulse from the vessels which contain it." A similar fact to this has been formerly stated with regard to the circulation in plants (§ 290). "How differently circumstanced are the Mollusca. The inert Tunicata, the lowest of the Molluscous classes, fixed like plants upon the sea-beaten cliffs, and in which we can scarcely discover a trace of life, enclose in their motionless carcase a heart as highly developed as that of the Crustacea, the highest of the Articulated classes; and if they did not, their blood would soon stagnate in the complicated labyrinth of vessels and organs through which it has to pass. The slow-creeping snail that feeds upon the turf, has a heart as complicated as that of the red-blooded vertebrated fish which bounds with such velocity through the deep. It is because the fish is muscular and active in every point, that it requires no more heart than a snail to keep up the necessary movements of its blood."

intestine; and probably in its distribution on its walls, performs the function of nutritive absorption, for which no more special apparatus is yet evolved.* In the CONCHIFERA we find the circulation carried on upon the same general plan, but the central organs are more highly developed. The ventricle or impelling cavity of the heart is a distinct sac, of which the walls are formed by muscular fibres interlacing in every direction, and even projecting into the interior. From this, the blood, which as in most other Molluscs is of a bluish white colour, is sent by two principal arterial trunks to the system at large; returning from its capillaries by the venous canals, it is conveyed to the gills, where it is exposed to the action of the air contained in the surrounding water; and it is finally returned to the heart by two large trunks, which do not enter the ventricle, but terminate in auricles, of which one is usually placed on each side. Although the auricular cavity is thus double, however, it is not to be regarded as analogous to the two auricles of warm-blooded animals, of which one receives the blood from the system at large, and the other that which is transmitted from the lungs; since here the two auricles have the same function, being both pulmonary, and being merely repetitions of one another, separated for the sake of convenience. In the *Oyster*, in fact, they are united into a single cavity; whilst in another tribe, the *Archidæ*, the ventricle is divided like the auricle, in conformity with the breadth of the back of the animal, and the consequent separation of the gills from one another.

306. Among the GASTEROPODA we find the same general arrangement of the vascular system; but the situation of its own individual parts is greatly varied in different species, owing to the different conditions of their respiratory system; some being modified for an aquatic life, and some to inhabit the surface of the land. In the Snail, which belongs to the latter tribe, and which, instead of having gills, is provided with a pulmonary cavity for the admission of air to the interior (§ 391), the heart is formed, as in the Conchifera, of an auricular and a ventricular sac; the latter is the stronger of the two, and the muscular bands which are interwoven in its coats project slightly into its cavity. The blood which is propelled from it by one principal arterial trunk or aorta, is distributed to the various organs of the body, and is transmitted from them by great veins, to the plexus of vessels distributed on the pulmonary sac; after here undergoing the necessary aeration, it is returned to the auricle, whence it passes

* Some of the compound Tunicata are connected together, like Polypes, by a hollow stem, in which a circulation of fluid (manifestly influenced by that of the individuals) takes place. The motion of the globules indicates a double current, of which one passes towards the heart of each individual, and the contrary one in the direction of another; the direction of the currents appeared to Mr. Lister (Phil. Trans. 1834) to be reversed every two minutes or less. In these compound Ascidiæ, the blood appears to pass at once from the heart to the gills, instead of traversing the system first, as in the solitary species. When one of them is separated from the common stem, its circulation goes on in an independent manner; but the alternation of the directions still continues.

into the ventricle by a valve formed of two pieces. Many curious varieties in the structure of the vascular system found in this group might be enumerated; but as these are principally connected with the position of the respiratory organs, more need not here be said respecting them. In all these Molluscous classes, we see the liver developed in a very high degree, and supplied with blood by a large arterial trunk. We shall subsequently find that the function of the liver is in part supplementary to that of the respiratory organs; and that it is in general most active when the changes for which the latter are adapted cannot, from any cause, be performed with sufficient energy. In some of the Gasteropoda, as in the Conchifera in general, the auricle is double; and, in a few genera, even the ventricle is partly divided by the intestine which passes through it. A general plan of the circulation in these tribes is given in Fig. 117.

307. Hitherto we have seen the respiratory system, whether branchial (in the form of gills) or pulmonary (composed of air-sacs), interposed between the capillaries of the system and the central propelling cavity; the veins which collect the blood from the different organs of the body uniting only to separate again, without any fresh impulse being given to their contents. The only instance of the interposition of anything like an impelling cavity between the veins of the system and the respiratory vessels, was seen in the Crustacea, where the venous sinuses situated at the commencement of the branchial arches may be regarded as so many repetitions of a simple form of a respiratory heart. In the class of Fishes, it will be seen that the heart is entirely respiratory, the arterial trunk which proceeds from it being distributed at once to the gills, and the blood which has been aerated in them being returned into a systemic artery or aorta, whence it proceeds to the body at large. In the higher CEPHALOPODA we observe a curious form of the circulating apparatus, which manifestly establishes the transition between that of the Mollusca in general, and that which is peculiar to Fishes. The systemic heart consists of only one cavity or ventricle, which is usually of a globular form, tolerably strong and muscular, and exhibiting bundles of fibres *(carneæ columnæ)* projecting into its cavity (Fig. 118), as well as distinct valves protecting the mouths of the vessels which open into it. The aorta which proceeds from it, distributes arterial blood to the general system; and this is returned by means of the venous trunks, not immediately to the gills, as in the other Mollusca, but to two superadded impelling cavities, one of which is situated in connection with each row of gills. These branchial ventricles are less powerful than that which propels the blood through the system; but they are still sufficiently muscular and contractile to accelerate the circulation through the respiratory organs, and thus to prepare the blood for the maintenance of the increased muscular exertions which are required for the superior locomotive powers of these animals, as well as for

the general activity of the functions of their highly-organised bodies (Fig. 119).

308. Here therefore we have, sketched out as it were, the complicated form of the vascular system in warm-blooded animals possessed of a complete double circulation; the trunks which convey the blood to the respiratory organs being furnished, like that which distributes it to the system at large, with an impelling cavity, by which a constant and regular current is maintained. This structure, however, is peculiar to that order of Cephalopoda which, in the symmetrical distribution of its organs, its deficiency of external shell, and its possession of a rudimentary internal skeleton, as well as in other particulars, exhibits so many points of resemblance to Fishes (§ 96). In the *Nautilus* tribe, on the other hand, the general structure is more analogous to that of the other Molluscs: and accordingly we find, from the account of Mr. Owen, that the vascular system presents nearly the same arrangement as in the Gasteropoda. The veins that return the blood from the system enter a common sinus, which has not, however, a muscular character, and does not possess contractile powers; and from this the branchial vessels proceed, which, after exposing the blood to the respiratory surface, conduct it back to the heart or systemic ventricle.*

309. Although in FISHES we find the same simple conformation of the heart as that which exists in the Molluscous classes, the alteration in its position, relatively to the other parts of the vascular system, occasions its influence on the function of the circulation to be greatly modified (Fig. 120). The blood which is expelled from the single ventricle is carried at once to the gills, the principal trunk subdividing into four or five branches on each side, which run along the branchial arches (§ 405), sending ramifications to every filament. After being thus aerated, it is collected by confluent vessels into the great systemic artery, which then distributes it to the different organs of the body; and thence it is returned to the auricle by the veins, which before entering it exhibit large dilatations or sinuses. (Similar cavities exist among the Cephalopoda.) Although this circle appears sufficiently simple in its character, it yet possesses some peculiarities which are worth notice, especially as they seem to foreshadow more important modifications in higher classes. Two or three small arteries are usually seen passing off from the branchial arches, so as to convey the pure aerated blood directly to the head, instead of transmitting it to the general systemic trunk. It will be hereafter shown that a

* It is not a little curious that the principal vein, just before entering the sinus, should communicate with the abdominal cavity by small apertures existing between the muscular fibres which traverse it, just as in the Aplysia. From various parts of the venous system, both in the Nautilus and in the Cuttle-fish, a curious series of follicles or little sacs is seen to proceed, forming spongy masses, sometimes of considerable size. The use of these is not certainly known, some regarding them as secreting organs, and others as temporary reservoirs of venous blood, like those which are found in the Cetacea and other diving animals.

similar provision exists in the Crocodile, and has a very important purpose in its economy; and that the same condition is manifested up to the termination of the embryo state of the higher Vertebrata, including the human species. Although we still find the respiratory and general circulation united in this class, they hold the same relation to one another as in the classes in which a complete double circulation exists, whose heart possesses four cavities instead of two. The passage of blood through the respiratory organs is sometimes called the "lesser circulation;" but there is more than one instance in the animal economy, in which the circulating fluid is made to pass through a circuitous track for the purpose of being purified by the elimination of some of its contents; and these would be alike deserving of the term. Thus, in Fishes the blood which is being returned to the heart from the tail and posterior part of the body, is transmitted through large venous trunks, partly to the liver, and partly to the kidneys, (sometimes almost entirely to the latter), in which organs these vessels ramify for the purpose of causing the separation of their peculiar secretions. After this process has taken place, the blood is conveyed to the heart by large venous trunks into which the smaller branches again unite. Thus, the *portal* circulation, as it is termed, holds precisely the same relation to the general circulation in Fishes, as did the respiratory circulation in the Mollusca; being interposed, for the purification of the blood which has circulated through the system, between its capillaries and the heart. It has not any special impelling organ for the purpose of transmitting the blood through it; unless a contractile portion which has been described as existing in the caudal vein of the Eel can be regarded as subservient to this function. This portal circulation exists in the same form in Reptiles: but in Birds and Mammalia the kidneys, like other organs, are supplied with arterial blood from which their secretion is formed; still the liver is connected with the venous system, and the portal circulation continues to have an important office in the purification of the blood,—an office which seems especially necessary in the fœtus before the action of the lungs has commenced.

310. Quitting now those classes which are modified for existing in water and passing on to the Reptiles, Birds, and Mammalia, we find that very important modifications of the circulating system are necessary to adapt the animal to the conditions of atmospheric respiration. It is evident that the blood will be aerated much more rapidly when exposed to the air itself, than when merely submitted to the small quantity which is diffused through the watery element. If, therefore, the whole amount of the circulating fluid be thus exposed, the changes which it undergoes will be performed with such increased energy that, if the other vital processes be made to conform to them, a warm-blooded animal is produced at once. But as the REPTILES are intended to lead a life of comparative inertness, and to exist in circumstances which would be fatal to animals of higher

organisation, the respiratory process is reduced in amount by the peculiar structure of the vascular system now to be described. The single ventricle of the heart gives off arterial trunks which pass both to the lungs and to the system at large; so that a part of the blood which has been expelled by each stroke is sent to supply the requirements of the nutritive system, and a part is separated for aeration. The pure arterialised blood which returns from the lung is conveyed to one auricle, whilst the venous blood which is transmitted by the systemic veins enters the other; these two auricles are hence not repetitions of one another, but have distinct functions. Both empty themselves into the ventricle, where the blood derived from these different sources is mixed, and from which one part is again sent to the body, and another transmitted to the lungs (Fig. 121).

311. This is the general type of the circulating system in the class of Reptiles, but there are some very curious modifications of it, which connect it with the vascular apparatus of Fishes on one hand, and with that of Birds and Mammalia on the other. The connection with Fishes, it is evident, will be established by the order *Batrachia* or Amphibia, which in their early or larva condition are in every respect analogous to the members of that class. Their circulation is for a time performed exactly upon the same plan, the blood being transmitted from the simple bilocular heart to the branchial arches, and after aeration being circulated through the system. The transition from this condition of the vascular organs, to that which they present in the perfect Reptile state of the animal, when they are conformable to the general type of the class, is so curious as to be worth a some what minutedescription; more especially as, in all the higher animals, a series of changes precisely analogous takes place during the early stages of their development. It will be rendered intelligible by the accompanying Figures 122-4. In Fig. 122 is seen the arrangement of the parts before the metamorphosis has commenced. Three branchial trunks (1, 2, 3,) pass off on each side of the heart, terminating in a minute capillary network which is contained in the branchial arches, and by which the blood is aerated during the aquatic existence of the animal; from this network the returning vessels take their origin, which unite into trunks, one for each gill; and of these the first supplies the head, while the second and third join to form the great systemic artery, A, as in fishes. But besides these vessels, there are some small undeveloped branches, which establish a communication between each branchial artery and the returning trunk that corresponds with it. There is also a fourth small trunk, 4, given off from the heart, which unites with another small branch from the aorta, to be distributed upon the (as yet) rudimentary lungs. After the metamorphosis has begun, however, by which the animal from a fish has to be converted into a reptile, the branches that connect the arteries of the gills with their returning trunks are much increased in size, so that a large part of the blood flows continuously through them

without being sent to the gills at all, and the branchial vessels are themselves relatively diminished; at the same time, the fourth trunk, which was before the smallest, becomes the largest, so that an increased proportion of blood is sent to the lungs. By a continuance of these changes, the branchial vessels gradually become obliterated, and the communicating branches, which were at first like secondary or irregular channels, now form part of the continuous line of the circulation, the upper one sending off the cerebral vessels, the second and third uniting to supply the trunk, and the fourth passing as before to the lungs.

312. In the *Proteus* the arrangement of the vascular system permanently resembles that which has been represented as intermediate between the larva and perfect condition of the frog. This animal is provided with lungs slightly developed, as well as with permanent gills; and the blood which is expelled from the ventricle is partly transmitted through the gills, partly finds its way directly into the aorta by means of the communicating branches, and a small quantity is transmitted to the lungs; the latter is returned perfectly arterialised to the pulmonary auricle, and is afterwards mixed in the ventricle with the venous blood transmitted to the systemic auricle. In many of the higher Reptiles we find not only two auricles, but the cavity of the ventricle more or less perfectly divided into two; sometimes the septum is complete, as in the Crocodile; and in other cases it affords only a partial separation, which is still perhaps sufficient to modify the direction of the currents of the blood. Thus, in the *Lacerta ocellata* (spotted lizard) where the ventricle is partly divided, the right side of it, into which the systemic auricle discharges itself, principally gives off the pulmonary trunks, so that a large proportion of the venous blood returned from the system is transmitted to the lungs for aeration; and this being returned to the pulmonic auricle is conveyed to the left side from which the systemic arteries proceed. As long as there is any direct communication, however, between the two sides of the heart, it is obvious that a part of the blood returned from the systemic veins may be sent immediately into the aortic trunks without being previously arterialised; and in proportion to the degree in which the septum is complete, will be the approach of the animal towards the condition of the warm-blooded Vertebrata. The distribution of the vessels, however, has a considerable effect upon the character of the fluid with which individual organs are supplied; for in Reptiles which manifest this separation to a considerable extent, a part of the blood transmitted to the system has still a venous character, whilst that which is furnished to the brain and upper part of the body is purely arterial. The contrivance by which this is effected is curious and interesting. The aortic trunk does not arise singly, but by two origins, one of which is connected with the right and the other with the left side of the ventricle; the latter receives chiefly the arterial blood from the left or pulmonary

auricle, and this gives off branches which convey it without admixture to the head; while the main trunk passes on to unite with the second aortic arch that arose from the right side of the heart, and consequently is filled with blood almost entirely venous, which has been discharged from the system into the right auricle. This second arch, before its union with the first, however, gives off a large branch which is distributed to the intestines and other viscera, and which, therefore, contains venous blood with little admixture of arterial; the common aortic trunk formed by the union of the two arches conveys mixed arterial and venous blood to the remainder of the trunk and members. It is beautiful to observe how by these simple contrivances the greatest economy of material is obtained, whilst each organ is supplied with blood of a character best fitted to maintain its functions.

313. The *Crocodile* presents us with a condition of the vascular system still more allied to that of warm-blooded Vertebrata; the ventricular septum being complete, and the circulation, as far as the heart is concerned, being truly double. Still, however, whilst the principal aortic trunk arises from the left ventricle, which contains nothing but arterialised blood, a second arch arises from the right (or venous side) along with the pulmonary artery of which it might almost be considered a branch; and this, after giving off its intestinal branches, enters the first trunk, which has already furnished the cerebral arteries with pure arterial blood, and transmits the mixed fluid to the rest of the system (Fig. 125). There is another communication between the trunks arising from the two sides of the heart, by means of an aperture which passes through their adjoining walls just after their origin; so that although the blood in the heart is entirely venous on one side and arterial on the other, it undergoes admixture in the vessels according to the character of the functions to which it is to minister. We shall presently see a remarkable analogy to this distribution of the vascular system, exhibited in the fœtal condition of Birds and Mammalia.

314. In the highest form of the circulating system, that possessed by the warm-blooded Vertebrata, there is a complete double circulation of the blood, each portion of it which has passed through the capillaries of the system being aerated in the lungs, before being again distributed to the body. This is effected by a form of the vascular apparatus of which we saw a sketch in the Cephalopoda, and to which a near approach is exhibited by the higher Reptiles. The heart consists of four cavities, two auricles and two ventricles; those of the right or venous side having no direct communication with those of the left or arterial side; and the vessels proceeding from them being entirely distinct, and having no connection whatever except at their capillary terminations. The blood transmitted by the great veins of the system to the *right* auricle or receiving cavity, having passed into the ventricle or propelling cavity, is transmitted

by it through the pulmonary arteries to the lungs of the two sides.* After being there arterialised by exposure to the atmosphere, it is brought back to the *left* auricle; and having been poured by it into the corresponding ventricle, is transmitted by the great systemic artery or aorta to the most distant parts of the body (Fig. 126). The heart is therefore completely duplex in structure, and, so far as its functions are concerned, might be regarded as consisting of two distinct portions; for economy of material, however, these are united, the septum of the ventricles serving as the wall to each. In the Dugong (one of the Whale tribe) however, the heart is bifid, and presents this division into two separate organs not only functionally but structurally (Fig. 127).

315. Various peculiarities in the distribution of the vascular system which are presented by different orders of Quadrupeds and Birds, would be worth notice if our limits permitted. Of these one of the most remarkable is the modification both of the venous and arterial trunks existing in the Cetacea and other diving animals, which are occasionally prevented from respiring for some time, and in which, therefore, the arterialisation of the blood is checked. Various arteries of the trunk are here found to assume a ramified and convoluted form, so that a large quantity of blood may be retained in the reservoirs formed by these plexuses; whilst the venous trunks exhibit similar dilatations, capable of being distended with the blood which has been transmitted through the system, so as to prevent the heart being loaded with the impure fluid, whilst the lungs have not the power of arterialising it. In some diving animals this object is effected, not so much by a number of venous plexuses, as by a single great dilatation of the vena cava before it enters the heart. Frequently the force with which the blood is sent to particular organs seems to be purposely diminished by the division of the trunk that conveys it into a number of smaller vessels, which, after a tortuous course, unite again and are distributed in the usual manner. A structure of this kind is found in the arteries of the brain of the long-necked grazing animals, to which the blood would be transmitted with too great an impetus, owing to the additional influence of gravitation, were it not retarded by this contrivance. A similar distribution of the arteries is found in the trunks supplying the limbs of the Sloths, and of other animals which resemble them in tardiness of movement. In other cases, the arterial canals are specially protected from compression by surrounding organs, in order that

* In must be borne in mind here and elsewhere that the term *artery* is used to denote a vascular tube carrying blood *from* the heart, whilst the word *vein* designates one which conveys it *towards* the heart: but that *arterial blood* means that which has been rendered florid by the respiratory process (§ 418) in whatever direction it may be travelling; and that by *venous blood* is meant the dark impure fluid of which the vital properties have been impaired by circulation through the capillaries of the system. The pulmonary *arteries* convey *venous* blood from the heart to the lungs; and the pulmonary *veins* return *arterial* blood from the lungs to the heart.

there may be no obstruction to the passage of blood through them, and that they may be protected from injury; thus, in the fore leg of the Lion, where all possible force and energy is to be attained, the main artery is made to pass through a perforation in the bone, that it may be secured from the pressure of the rigid muscles, which, when in a state of contraction, might otherwise have altogether checked the current through it. In most Quadrupeds, as in man, the right anterior extremity is more directly supplied with blood from the aorta than the left; so that the superior strength and activity of this limb is not altogether the result of habit and education, as some have supposed; in Birds, however, where any inequality in the powers of the two wings would have prevented the necessary regularity in the actions of flight, the aorta gives off its branches to the two sides with perfect equality. Some further peculiarities in the distribution of the arterial system will be hereafter noticed (§ 330).

316. Having now traced the vascular system to its highest form, it is proper to enquire how far this differs from the simple condition in which it was at first manifested. There can be no doubt that in the higher animals, possessed of a distinct muscular heart, *this* is the chief agent in keeping up, by its successive contractions and dilatations, the motion of the blood through the vessels. But a careful survey of all the phenomena of the circulation would seem to lead to the conclusion that the impulse of the heart is not the *only* means by which the motion of the blood is continued, but that the changes which this fluid undergoes in the capillaries have some share in its production, and have at any rate a very considerable modifying effect upon the quantity transmitted through the individual organs. We have seen that in Vegetables the nutritive circulation is entirely capillary; that in the lower Animals it is chiefly so; that even in Insects it appears but little dependent upon the action of the central recipient and impelling cavity; but that in the higher tribes the capillary power* is more and more subordinated to the heart's action. The following are some of the facts which appear to support the conclusion that, even in the highest animals, this capillary power is not obliterated, but is merely superseded by the energy of the central organ, which it was necessary to endow with an amount of force sufficient to govern and harmonise the numerous actions going on in different parts of the system.

* By using this expression, the author does not mean to imply that any motions of the capillary vessels are of mechanical assistance to the passage of fluid through them,—a doctrine which neither common sense nor experience in any degree support; but he merely employs it to designate the agent, whatever may be its nature, which is immediately concerned in the independent motion of the blood through the capillaries, and which is evidently the product of the organic changes it undergoes in them. According to Dr. Alison the movement is owing to a new set of *vital attractions and repulsions* to which these changes give rise; this must be regarded as a hypothetical explanation merely, and liable to the objection that, in the present state of our knowledge of *physical* causes, we are not entitled to declare that the effect is not due to these.

317. In many warm-blooded Vertebrata, and still more in the cold-blooded Reptiles, (amongst which the vitality of individual parts much longer survives injury to the general system), motion of blood in the capillaries has been seen to continue some time after the heart has ceased to act, or has been removed, or after the great vessels have been tied; and this motion may be immediately checked by certain applications to the parts themselves. After most kinds of slow natural death, the arterial trunks and left side of the heart are found to be comparatively empty, and the venous cavities full of blood. This effect has been ascribed to the contraction of the arterial tubes; but it is impossible that it can be altogether due to that cause, since their calibre is never found to have diminished in any very evident degree; it must rather result from the continuance of the capillary movement after the general systemic circulation has ceased. The continuance of various processes of secretion and even of nutrition subsequently to general or *somatic* death, affords an excellent proof of this lingering vitality; and it is scarcely possible that these can be maintained without some degree of capillary circulation. There are some kinds of sudden death, however, in which the vitality of the whole system appears to be simultaneously destroyed, and the blood remains in the vessels as it was at the moment of decease. Again, it has been stated that in an ampututed limb the circulation of blood through the capillaries has been seen to persevere (under the influence of heat) for ten or fifteen minutes. Microscopic examination of the circulation in the living animal discloses many irregularities in the capillary currents, which it is impossible to attribute to any influence derived from the vessels that supply them; thus, the velocity of two currents in neighbouring channels is often very different, their direction changes, and some of them even occasionally stop and recommence again without any perceptible mechanical cause.

318. Amongst the most remarkable proofs of the influence of the capillary circulation on the general distribution of the blood, is one derived from the observation of organs which undergo periodical changes in activity. Thus, when the uterus commences to develope itself during pregnancy, the capillary circulation is of course performed with unusual activity, and occasions an increased demand for blood, which is supplied by an increase in the diameter of the trunks that transmit fluid to the organ; and this is entirely independent of any increased energy in the heart's action, which would have affected the whole system alike. The same may be said of the occasional development of the mammæ for the secretion of milk; and of similar changes in other organs, of which the activity is periodical. In diseased states, also, of particular portions of the system, which do not occasion any appreciable alteration in the heart's action, the quantity of blood sent to the part is much increased, and the pulsation of the arterial trunk leading to it is evidently stronger than that

of any other vessels in the system. These phenomena, and many others which might be mentioned, are evidently analogous to one formerly mentioned as having been ascertained by experiments on plants (§ 289); and, when taken in connection, they seem to indicate without much doubt, that the quantity of blood sent to individual organs, and the force with which it is transmitted, vary more with the degree of attraction exercised upon it by the vital processes taking place in them, than with the *vis a tergo* derived from the impulsive power of the heart. Another remarkable proof of the influence of the capillary on the general circulation is derived from the phenomena of Asphyxia or suffocation; since it now seems distinctly ascertained that the check given to the circulation, and thence to all the other functions, arises from the stagnation of the blood in the capillaries of the lungs, by the cessation of that reaction between the fluid and the air, which seems requisite, not only to maintain its normal constitution and properties, but to promote its movement through the vessels (see *notes* to § 152, 212). Some other arguments for the independent nature of the capillary circulation, may be drawn from the spontaneous motions exhibited by the globules of the blood when removed from the body or liberated from vessels; but a more particular account of them will be given at a future time (§ 363).

319. In the development of the embryo of the higher vertebrated animals, moreover, there is a period at which a distinct movement of red blood is seen, before any pulsating vessel can be detected to possess an influence over it; and in the formation of new membranes, which is one of the results of inflammation, the lymph, that is poured out in a fluid state and gradually acquires a solid consistence, presents channels in which globules are seen to move before these become connected with the vessels of the neighbouring parts. Finally, instances not very unfrequently occur, of embryos having attained nearly their full development, which have been unpossessed of a heart, and in which the circulation has been, as it were, entirely capillary; and although in most, if not all, of these cases, the monster has been accompanied by a perfect child, the heart of which may have been suspected to have influenced its own circulation, yet in one of those most recently examined, the occurrence of this has been disproved. From a careful examination of the vascular system, it appeared impossible that the heart of the twin fœtus could have caused the movement of blood in the imperfect one; and this must, therefore, have been entirely similar to the circulation of elaborated sap in plants, being maintained by the nutritive changes occurring in the capillaries,—an effect not the less certain because we are as yet unable to explain it satisfactorily.*

* For the details of this interesting case, which was communicated by Dr. Houston, of Dublin, to the British Association, in 1836, see the British and Foreign Medical Review, vol. II., p. 596, and the Dublin Medical Journal for 1837.

320. The evolution of that circulating system which has been described as peculiar to the higher classes of Vertebrated animals, is not completed until the moment of birth; and the progressive changes which the vascular apparatus undergoes in the development of the fœtus of Birds and Mammalia afford a most beautiful illustration of the principles already laid down, respecting the correspondence between the transitory stages of each system in the higher animals, and the forms permanently exhibited by the lower. It has been seen that in the organs of circulation, as well as in all others, the tendency, as we rise from their lowest to their highest condition, is one of centralisation. In the simplest animals, as in plants, whatever motion of fluid takes place is effected by each individual part by and for itself; whilst in the complex and highly developed structures that occupy the other extremity of the scale, the development of a powerful organ of impulsion, the influence of which extends over the whole system, has superseded the diffused agency by which the circulation was previously maintained. This progress from a more general to a more special type is equally manifested in the vascular system of the embryo; and the analogy which thus arises between the forms it presents at different epochs of its development, and those presented by the lower tribes of animals, is not superficial only, but extends even to minute particulars. The eggs of Birds afford the best opportunity for studying the early changes which it undergoes, and these have been described with great minuteness; such a sketch of them only will here be given as will serve to demonstrate the principles alluded to. On the surface of the yolk-bag of a fresh egg, a little semi-opake spot about $\frac{1}{8}$ of an inch in diameter may be readily detected; this is termed the *cicatricula* or germ-spot, and it is here that the first changes are performed in which the development of the embryo consists (§ 535). This afterwards extends itself into the *germinal membrane*, which gradually spreads over and encloses the yolk, and on the central portion of which, the embryo is developed. This membrane soon exhibits a subdivision into three laminæ, of which the middle one, termed the *vascular layer*, gives origin to the circulating apparatus, and the development of it alone will be here described.

321. During the early period of incubation, the thickened portion of the vascular layer that surrounds the germ becomes studded with numerous irregular points and marks of a dark yellow colour; and as incubation proceeds, these points become more apparent, and are gradually elongated into small lines, which are united together, first in small groups, and then into one network, so as to form what is called the *Vascular area.* The newly formed vessels, which are at first simply channelled out like the proper vessels of plants, gradually become more distinct, acquiring regular walls, and containing a fluid of a darker colour; the small branches of the network arrange themselves like the fibrils of a leaf on each side of the embryo, and terminate in two vessels which pass into its structure.

Towards the circumference of the area, the smaller ramifications open into a circular trunk which bounds the space (Fig. 128). The first rudiment of the heart appears about the 27th hour, and is of a tubular character, being formed by a longitudinal fold of the vascular layer; for some time it is simple and undivided, extending, however, through nearly the whole length of the embryo; but the posterior part may be regarded as corresponding with the future auricle, since prolongations may be perceived extending from that part into the transparent area, which indicate the place where the veins subsequently enter. Although the development has proceeded thus far at about the 35th hour, no motion of fluid is seen in the heart or vessels until the 38th or 40th hour. When the heart, which is evidently at this period strictly analogous to the dorsal vessel of the Annelida, first begins to pulsate, it contains only colourless fluid mixed with a few globules. A movement of the dark blood in the circumference of the vascular area is at the same time perceived; but this is independent of the contractions of the heart, and it is not until a subsequent period that such a communication is established between the heart and the distant vessels, that the dark fluid contained in them arrives at the central cavity, and is propelled by its pulsations. This fact, which has a very important bearing on the theory of the circulation, and which has been denied by some observers (amongst others by Dr. Allen Thomson), appears to have been positively established by the latest researches of Von Baer.*

322. The contraction of this dorsal vessel (for so it may be termed) begins, as in the Annelida, at its posterior extremity, and gradually extends itself to the anterior; but between the 40th and 50th hours, a separation in its parts may be observed, which is effected by a constriction round the middle of the tube, and the dilatation of the posterior portion into an auricular sac, and that of the anterior into a ventricular cavity. Between the 50th and 60th hours, the circulation of the blood in the vascular area becomes more vigorous, and the action of the ventricle is no longer continuous with that of the auricle, but seems to succeed it at a separate period. At the same time the tube of the heart becomes more and more bent together until it is doubled; so that this organ now becomes much shorter relatively to the dimensions of the body, and is more confined to the portion of the trunk to which it is subsequently restricted. A change somewhat similar but less in amount has been shown by Mr. Newport to take place in the dorsal vessel of many insects

* He says that there is no doubt of the blood being formed before the vessels. The formation of the blood goes on in every part of the body; and when formed, it is put in motion by some unknown cause that impels it in the proper direction, until at length it reaches the central formation of blood, around which is developed a tubular canal afterwards to be further modified and changed into a heart. The first motions of the blood are *towards* the heart, and consequently the first vessels formed are *veins;* a fact of itself sufficient to disprove the hypothesis that the motive power which presides over the circulation resides exclusively in the ventricles of the heart. Uber Entwickelungsgeschicte der Thiere, &c. Königsberg, 1837. Part II. p. 126.

at the time of their last metamorphosis.* The convex side of the curve which the tube presents (Fig. 129) is that which subsequently becomes the apex or point of the heart; and, between the 60th and 70th hours, this is seen to project forwards from the breast of the embryo, much in the situation it subsequently occupies. About the same time, the texture of the auricle differs considerably from that of the ventricle; the auricle retaining the thin and membranous walls which it at first possessed; while the ventricle has become stronger and thicker, both its internal and external surfaces being marked by the interlacement of muscular fibres, as in the higher Mollusca. About the 65th hour, the development of the heart may be regarded as corresponding with that of the fish; the auricle and ventricle being perfectly distinct, but their cavities as yet quite single. The heart of the dog at the 21st day bears a great resemblance to that of the chick at the 55th or 60th hour; it consists of a membranous tube twisted on itself and partially divided into two principal cavities, besides the bulb or dilatation which at this period is found at the commencement of the aorta, and which is peculiarly developed in Fishes.

323. The blood-vessels which are first observed in the body of the embryo, as well as in the vascular area, appear formed in isolated points, which gradually coalesce so as to form tubes; no difference is at first observed between the characters of the arteries and those of the veins, and these are only to be distinguished by the direction of the currents of blood circulating through them. Subsequently, however, (about the fourth or fifth day of incubation), the coats of the arteries begin to appear thicker than those of the veins, and the distinction between them soon becomes evident. After the principal vessels are formed, the development of new ones no longer appears to take place in disunited points, but to be effected by the prolongation of loops from those already existing. This process has been described by several observers, as witnessed in the finny tail and external gills of the common tadpole and water newt. In these animals, the course of the blood is at first very simple. In the early stages of development there is no capillary network on the tail, but a simple arterial trunk which runs to the end of it, and there joins a returning vein. At a later period, it is well known that the tail is covered by a network of minute vessels, communicating with the primary artery and vein, in which the blood is conveyed through the whole substance of the organ. The development of these vessels has been shown to be owing to the prolongation of communicating branches formed between the primary trunks. These communicating branches pass at first directly from the artery to the vein; but they become gradually longer and assume a looped form, extending from the middle to the lateral expanded portions of the tail; other loops are formed in succession from these, and new ones again from them, until, in the course of ten or more days, the

* Roget's Physiology. Vol. II. p. 245.

whole of the finny part of the tail is covered by beautiful minute arteries and veins. The loop of the vessel, when short and newly formed, has at first more the appearance of artery than vein, as the blood passes through it in jerks; as the loop elongates, however, and new branches proceed from it, the blood moves in jerks only in that part of the loop which communicates with the arterial trunk, whilst, in the part connected with the returning vein, the stream of blood becomes uniform.

324. The development of the vessels in the filamentous gills of the aquatic Salamander takes place on precisely the same plan; and their distribution in the leaf-like gills of the adult *Proteus* (Fig. 130) is evidently the result of a similar process. A corresponding series of changes has been observed in other organs. Thus, the anterior extremities of the *Salamander* commence as little tubercles sprouting behind the head and almost destitute of circulating blood. Soon after their appearance, a single vessel is seen winding round their extremities, which returns to the body without giving off any branches. The toes are soon observed to bud forth from the end of the limb, and each of them receives a small loop from the original vessel. Communicating branches are likewise thrown across the joints, and as the limb becomes larger, numerous capillary vessels are formed in the same manner as the primitive trunks. The same appearances have been observed in the first evolution of the extremities of the chick, and also in the embryo of the rabbit and other mammiferous animals; so that there appears reason to believe that, after the circulation has once been fully established, the development of new vessels takes place universally on this plan, except where their formation is the result of a diseased action (§ 364). Some microscopic observers state that new loops may occasionally be seen to form during the ordinary processes of nutrition, in parts which have already attained their full development.

325. Having traced the evolution of the heart of the chick up to the grade which it presents in fishes, we may now enquire what is the condition of the other parts of the vascular system at the same time. At the end of the second day, the *aorta*, which arises by a single trunk, is seen to have divided into two canals (1, 1, Fig. 131) which separate from one another to enclose the pharynx, and then unite again to form the trunk, A, which passes down the spine. During the first half of the third day (about the 60th hour), a second pair of arches, 2, 2, is formed, which encompasses the pharynx in the same manner; and towards the end of the third day, two other pairs of vascular arches, 3, 3 and 4, 4, are formed; to that the pharynx is now encompassed by four pairs of vessels which unite again to supply the general circulation. These evidently correspond with the branchial arteries of fishes, although no respiratory apparatus is connected with them; and in fact the distribution of the vascular system of the bird on the fourth and fifth days exactly resembles that presented by

many cartilaginous Fishes, as well as by the tadpoles of the Batrachia. The first arch is obliterated about the end of the fourth day; but a vessel which is sent from it to the head and neighbouring parts, and which afterwards becomes the carotid artery, *c*, continues to be supplied through a communicating vessel, 6, from the second arch. While the first pair is being obliterated, a fifth, 5, is formed behind the four which had previously existed, proceeding in the same manner as the fourth from the ascending to the descending aorta. On the fourth day, the second arch also becomes less, and on the fifth day is wholly obliterated; whilst the third and fourth become stronger. From the third arch, now the most anterior of those remaining, the arteries are given off which supply the upper extremities, *b*, *b;* and the vessels of the head are now brought into connection with it, by means of the communicating branch, 7, which previously joined the third with the second arch. When these vessels are fully developed, the branch, 8, by which these arches formerly sent their blood into the aorta, shrinks and gradually disappears, so that by about the 13th or 14th day the whole of the blood sent through the two anterior branches is carried to the head and upper extremities, instead of being transmitted to the descending aorta as before. There now only remain the fourth and fifth pair of branchial arches, the development of which into the aorta and pulmonary arteries will be described in connection with the changes which are at the same time going on in the heart.

326. During the fourth day, the cavities of the heart begin to be divided for the separation of the right and left auricles and ventricles. About the eightieth hour the commencement of the division of the auricle is indicated externally by the appearance of a dark line on the upper part of its wall; and this, after a few hours, is perceived to be due to a contraction, which, increasing downwards across the cavity, divides it into two nearly spherical sacs. Of these the right is at first much the largest and receives the great systemic veins; the left has then the aspect of a mere appendage to the right, but it subsequently receives the veins from the lungs when these organs are developed, and attains an increased size. The septum between the auricles is by no means completed at once; a large aperture (which subsequently becomes the *foramen ovale)* exists for some time at its lower part, so that the ventricle continues to communicate freely with both auricles. This passage is afterwards closed by the prolongation of a valvular fold which meets it in the opposite direction; it remains pervious, however, until the animal begins to respire by the lungs, and sometimes is not completely obliterated even then. From late observations it would appear that the division of the ventricle commences some time before that of the auricle. Although some variation exists in the statements of different authors on the mode in which this is effected, the general fact appears to be that a septum is gradually developed within the cavity by a projection arising from its inner wall; and this progress-

ively acquires firmness, and rises higher up, until it reaches the entrance to the bulb of the aorta, where some communication exists for a day or two longer. At last, however, the division is complete, and the inter-ventricular septum becomes continuous with the inter-auricular, so that the heart may be regarded as completely a double organ. The progressive stages presented in the development of this septum are evidently analogous to its permanent conditions in the various species of Reptiles (311-3). The changes which occur in the heart of the Mammalia are of a precisely similar character; and, as they take place more slowly, they may be watched with greater precision. Soon after the septum of the ventricles begins to be formed in the interior, there appears a corresponding notch on the exterior, which, as it gradually deepens, renders the apex of the heart double. This notch between the right and left ventricles continues to become deeper until about the eighth week in the human embryo, when the two ventricles are quite separated from one another, except at their bases (Fig. 132); this fact is very interesting from its relation with the similar permanent form presented by the heart of the Dugong. At this period, the internal septum is still deficient, so that the ventricular cavities communicate with each other, as in the chick on the fourth day. After the eighth week, however, the septum is complete, so that the cavities are entirely insulated; whilst at the same time their external walls become more connected towards their bases, and the notch between them is diminished; and at the end of the third month the ventricles are very little separated from one another, though the place where the notch previously existed is still strongly marked.

327. Returning again to the distribution of the arterial trunks, we are now prepared to follow their final modification, by which they are adapted to the existence which the individual is soon to commence as an air-breathing animal. The first, second, and third branchial arches have been shown to be replaced by the brachial and carotid arteries, and to have lost all communication with the aorta except at its commencement, where they arise with the other trunks from its dilated bulb. This remains a single cavity after the ventricles are distinct; but towards the end of the fifth or the beginning of the sixth day in the chick, the bulb becomes flattened, and the opposite sides adhere together so as to separate it into two tubes running side by side. Of these, one communicates with the left, and the other with the right ventricle. The former, which subsequently becomes the aorta, is continuous with the fourth branchial arch on the right side only; but from this the carotid and brachial arteries arise by two principal trunks (Fig. 131). This arch becomes gradually larger, so as to form the freest mode of communication between the heart and the descending aorta; it subsequently becomes, in fact, the arch of the aorta. The trunk, which is connected with the right ventricle, on the other hand, and which subsequently becomes the pulmonary

artery, transmits its blood through the fourth arch of the left side (the two primary tubes twisting round each other) and the two fifth arches; the latter were seen in the tadpole to pass to the lungs exclusively from the first, and to increase in development only as the supplies of blood to the branchiæ were cut off. The fifth arch on the left side is gradually obliterated, so that the pulmonary artery, *P*, is ultimately formed by the fourth arch of the left side and the fifth arch of the right. The original prolongation of the former trunk, 9, to meet the descending aorta, still remains; so that a portion of the blood sent from the right ventricle is transmitted through this communicating branch directly into the descending aorta, just as in the adult crocodile. After the first inspiration, however, the whole of the blood transmitted through the pulmonary artery passes into the lungs, and does not enter the aorta until it has been returned to the heart; and this communicating vessel soon shrinks and becomes impervious. The general plan of the changes which occur in the vascular system of the Mammalia is the same as that which has been described in Birds; the differences being only in detail,—as for instance that the aortic arch is formed not from the right but from the left branchial vessel.

328. Up to the period of the hatching of the egg in Birds, and the separation of the fœtus from the parent in the Mammalia, the circulation retains some peculiarities characteristic of the inferior type which is permanent in the reptile tribes. Of the blood which is brought by the venous trunks to the right auricle, part has been purified by transmission to the respiratory surface (the membrane lining the egg in birds, and that forming the placenta in mammalia), whilst a part has been vitiated by circulation through the system. The former is brought from the abdomen by the ascending vena cava, mixed with the blood which has circulated through the lower extremities; whilst the descending cava brings back that which has passed through the capillaries of the head and upper extremities, and which, having received no admixture of arterial blood, is not fit to be again transmitted in the same condition. It will be recollected that a communication still exists between the two auricles, the foramen ovale yet remaining pervious; and by a fold of the lining membrane of the right auricle, forming the Eustachian valve, the ascending and descending currents are so directed that the former (consisting of the most highly arterialised blood) passes at once into the left auricle, whilst the latter flows into the right ventricle. From the left auricle, the arterial blood is propelled into the left ventricle, and thence through the arch of the aorta to the vessels of the head and upper extremities, a comparatively small part finding its way into the descending aorta. The venous current is propelled through the pulmonary artery; but the lungs not yet being expanded, little of it is transmitted to these organs, and the greater part finds its way through the ductus arteriosus

into the descending aorta, where it mixes with the remainder of the first mentioned portion. This trunk not only supplies the viscera and lower extremities, (which are thus seen to receive, as in reptiles, blood of which only a portion has been oxygenated), but sends a large proportion of its contents to the umbilical vessels, by which it is conveyed to the oxygenating organ, and returned again to the venous trunk of the abdomen. The peculiar course taken by the blood through the heart, which was suspected from anatomical investigation, has been recently demonstrated by means of coloured injections of plaster-of-paris by Dr. J. Reid.* Another peculiarity in the fœtal circulation is the mode in which the blood passes through the liver. In the adult Mammalia, as in Birds and all other Vertebrata, the blood which has circulated through the intestinal viscera is collected into a large venous trunk, the *vena porta*, which subdivides again into capillary vessels in the liver; the object of this arrangement is not the nutrition of that organ, which is effected by the branches of the hepatic artery, but the supply of its secreting surface for the elimination of the bile; and the hepatic vein consequently receives, and conveys to the ascending vena cava, both the blood which has been transmitted through the nutritive capillaries of the liver by the hepatic artery, and that which, after ramifying through the nutritive capillaries of the intestines, has traversed the secreting capillaries of the liver. The vena porta in the fœtus, however, receives not only the venous blood of its abdominal viscera, but the arterial blood sent from the respiratory surface; and as it would not be desirable that the whole of this should pass through the liver before being transmitted to the heart, an immediate passage into the vena cava is provided for a part of it in the *ductus venosus*, which, not being required after birth, shrivels into a ligament.

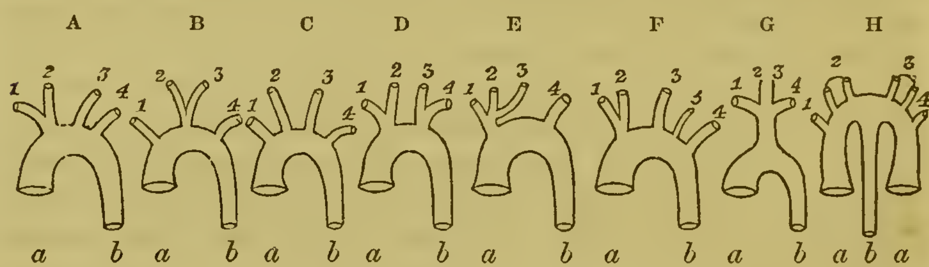
329. The knowledge of the different stages of the development of the vascular apparatus enables us to explain many of the malformations which it occasionally presents. One of the most common of these gives rise to the malady termed *cyanosis* or the blue disease; this results from the *foramen ovale* which establishes a communication between the auricles remaining open after pulmonary respiration has been established, so that a considerable portion of the blood transmitted to the right cavity passes into the left, without being previously arterialised by passage through the lungs. Persons thus affected have always a livid aspect, from the quantity of venous blood circulated through the arteries; they are deficient in muscular energy, and in power of generating heat, and they are seldom long lived. A consequence partly similar would probably have resulted from a curious malformation mentioned by Kilian, had the infant remained alive; in this case, the aortic arch had not been developed, so that the primary aortic trunk only gave off the vessels to

* Edinb. Med. and Surg. Journ. vol. xliii. pp. 11 and 308.

the head and upper extremities; whilst the communicating branch between the pulmonary artery and descending aorta, which usually is of a secondary character, constituting the ductus arteriosus, was here the only means by which the blood could be transmitted to the latter, so that the circulation through the lower part of the trunk and extremities would have been entirely venous. A malformation of this kind in a diminished degree has not been found incompatible with the continuance of life; several cases being on record in which the ductus arteriosus has remained pervious, and has brought part of the blood from the pulmonary artery to the descending aorta. Cyanosis is of course, as in the former instance, the result of this imperfect arterialisation; and the individual is reduced, as far as his vascular system is concerned, to the condition of the Crocodile. An arrest of development at an earlier period may cause still greater imperfections in the formation of the heart. Thus, the septum of the ventricles is sometimes found incomplete, the communication between the cavities usually occurring in the part which is last formed, and which in most reptiles remains open. In other cases it has been altogether wanting, although the aorta and pulmonary artery were both present and arose side by side from the common cavity; and this form of the circulating apparatus is evidently analogous to that presented by Reptiles in general. A still greater degradation in its character has been occasionally evinced; for several cases are now on record in which the heart has presented but two cavities, an auricle and a ventricle, and thus corresponds with that of the Fish; in one of these instances the child had lived for seven days, and its functions had been apparently but little disturbed. The occasional entire absence of the heart has already been noticed; and coexistent with this, there is always great deficiency in the other organs, the brain and sometimes the liver and stomach being undeveloped. The bifid character of the apex, which presents itself at an early period of the development of the heart, and is permanent in the Dugong, sometimes occurs as a malformation in the adult human subject; evidently resulting, like the others which have been mentioned, from an arrest of development. On similar principles some occasional peculiarities noticed in the distribution of the vessels may be accounted for, of which a striking example will be presently given. The Vena Cava is occasionally observed to consist of two parallel trunks, which are sometimes partially united, and then separate again; the explanation of this fact is different, and is to be sought for in the history of the development of the venous system in general. We have seen that in many of the lower animals, such as the Crustacea, where the arteries are perfect canals having distinct coats, the veins seem to be merely channels through the tissues having a much less definite character: in like manner, at an early period of the fœtal development of the higher animals, several small vessels are found where one vein subsequently exists; and, if the coalescence of these has been from

any cause checked, they will remain permanently separated to a greater or less extent.

330. Several interesting varieties have been detected in the arrangement of the principal trunks given off from the aorta; and though we cannot account for them on the principles already mentioned, it is not a little curious that nearly all of these irregular forms possess analogues in the arrangements which are peculiar to some or other of the Mammalia. The mode in which the cerebral and brachial vessels usually arise in the human subject is shown in the adjoined figure, A, where *a*, *b*, is the arch



of the aorta, 1 and 2 the trunks of the right carotid (which supplies the head) and the right subclavian (which is distributed to the upper extremity), arising by a common trunk—the arteria innominata; while the left carotid, 3, and the left subclavian, 4, arise separately. At B is seen a distribution which is rare in the human subject, the two carotids arising by a common trunk, and the right as well as the left subclavian being given off separately; this is the regular arrangement of branches in the Elephant. It is not so unusual for all the branches to arise from single trunks, as at C; and this appears to be the regular type in some of the Cetacea. Sometimes, again, there is an arteria innominata on each side, subsequently dividing into the carotid and subclavian, as at D; and on this plan the branches are distributed in the Bat tribe, and also in the Porpoise. A not unfrequent variety in the human subject, is for both carotids to arise with the right subclavian from a single trunk, as at E, the left subclavian coming off by itself; this is observable as the regular form among many animals, being common among the Monkey tribe, the Carnivora, the Rodentia, &c. Another variety which is not unfrequent is shown at F, the vertebral artery on the left side, 5, which usually arises from the subclavian, springing directly from the aorta; it is on this plan that the branches are given off in the Seal. A form which is very uncommon in man is that represented at G; here the aorta divides at once into an ascending vessel, from which the two subclavian and two carotid arteries arise, and a descending trunk; this is the regular distribution of the vessels in ruminating animals, and appears to be most general in Mammalia possessing a long neck. Lastly, at H, is seen a form which evidently results from an arrest of the usual changes in the arterial trunks

described in § 325, 7; the aorta continuing to possess a double arch, from the ascending part of which the subclavian, external carotid, and internal carotid arteries are given off on each side, the single descending trunk being formed by the union of the two original branches. This, it will be recollected, is the normal type of formation in Reptiles.*

CHAPTER VII.

On Interstitial Absorption.

331. The circulating system already described not only serves to convey to parts of the organism remote from the absorbent surface the alimentary materials required for the nutrition of their tissues: but, in the lower tribes of animals, it returns to the central reservoir the portion of the circulating fluid which has not been so employed; and is also the means of conveying to it, for the purpose of subsequent excretion, those particles of the solid structure which, from tendency to decomposition or some other cause, are not fit to be retained in it. Moreover, the general vascular system seems occasionally concerned in the absorption of fluid from the external surface as well as from the walls of the digestive cavity (§ 279). But in the Vertebrated classes, which possess a special set of vessels for the absorption of chyle from the intestines (§ 262), we also find a system of tubes of corresponding structure ramifying through every part of the system, to which the function of absorption seems more particularly delegated. The *lymphatics*, as they are termed, are distributed through almost every tissue in the body, and are believed to form a large proportion of the fibres of cellular structure; they are especially abundant beneath the skin, where they form a close network so universally diffused that if successfully injected it is scarcely possible to find a spot not traversed by them. The minutest of these tubes are, however, much larger than the capillary vessels connecting the arteries and veins; and it seems now generally allowed that they do not take their origin in them (as some have maintained), but that they commence, like the lacteals, without open extremities, their contents being derived by imbibition or endosmose from the surrounding tissues. The minute lymphatic canals unite, like the veins and lacteals, into larger trunks; and by these the fluid which is taken

* In the foregoing account of the development of the vascular system, the author has availed himself freely of the valuable papers of Dr. Allen Thomson, in the Edinb. Philos. Journal, vols. IX. and X.; in the sketch of the malformations of the heart, he has made use of the paper of Dr. Paget in the Edinb. Med. and Surg. Journal, vol. XXXVI.; and the last paragraph, with the accompanying figures, has been entirely derived from the magnificent work of Tiedemann on the Arteries.

up by the absorbent extremities, is conveyed to the principal veins. The number and mode of the communications between the lymphatic and venous systems differs in each class of animals; it will be seen that they are most numerous in Fishes, but that the separation between the two kinds of vessels becomes more complete, until, in Man and the higher Mammalia, the contents of the lymphatics are united with those of the lacteals, and are poured into the venous system by one trunk only.

332. The lymphatic system is exhibited in its simplest and most diffused form in FISHES, the lowest class in which it has been observed. Indeed it has not been detected in some of those vermiform species of which the conformation is so simple, and in which the traces of vertebrated structure are so slight. The minute vessels are distributed extensively through both the superficial aud deep-seated parts of the body; but their coats are peculiarly thin aud soft, and their tubes, which are destitute of valves, extremely distensible. Numerous plexuses are formed by the convolutions and auastomoses of their trunks, in different parts of the body, especially around the veins, which may be regarded as the first indications of the so-called glands which are presented in the higher classes. Although a considerable proportion of the lymphatic trunks unite with the lacteal vessels to form principal canals (corresponding with the thoracic duct in higher animals), which empty their contents into the systemic veins near the heart, there are many other communicatious between the two systems, as Fohmann appears to have satisfactorily demonstrated. A pulsating cavity has been described by Dr. M. Hall, as belonging to the vein of the tail in the eel; but it is more probably an appendage of the lymphatic system, like those to be presently described in Reptiles.

333. REPTILES present several interesting peculiarities in the conformation of their lymphatic system. As in fishes, the vessels are geuerally destitute of valves, though these may occasionally be observed in the large trunks; and the extended plexuses do not yet exhibit the concentration which they present in Birds and Mammalia. In this class, pulsating dilatations of the lymphatic trunks, or *lymphatic hearts*, have been discovered in different parts of the body. In the frog there are two pairs of these, one situated just under the skin, through which its pulsations are readily seen in the living animal, immediately behind the hip joint; and the other pair is more deeply seated at the upper part of the chest. The former receive lymph from the posterior part of the body, and pour it into the veins proceeding from the same part; the latter collect that which is transmitted from the anterior part of the body and head, and empty their contents into the jugular vein. Their pulsations are totally independent of the heart and of the acts of respiration, since they continue after the removal of the former, and for an hour or two after the apparent death and complete dismemberment of the animal. Neither are they synchro-

nous with each other on the two sides of the body, nor always performed in the same space of time; for the pulsations are not only generally irregular, but sometimes exhibit long and frequent intermissions; when in constant action they occur about sixty times in a minute. A similar pair of vesicles has been detected in salamanders and lizards, where they are situated near the root of the tail, and are connected, in like manner, with the veins of the lower extremity; they have also been discovered in serpents, where they lie under the last rib. One of these, which has lately been described in the Python bivitatus, a large species, is represented laid open in Fig. 133. It is about nine lines in length and four lines in breadth; and has a thick muscular coat with four muscular columns running across its cavity. It communicates with three lymphatic trunks, and with two veins; and all the orifices are provided with valves formed by folds of the smooth membrane that lines the cavity. In the turtle, however, there is no communication between the pelvic veins and the lymphatic trunks, and these pulsating vesicles do not exist. In the Reptiles in general, the lymphatic system is stated by Panizza to attain a prodigious development, when its extent is contrasted with that of the blood-vessels: but this extension is probably rather apparent than real; and, like a similar extension of the respiratory system in insects and birds, arises from the want of that concentration which it elsewhere exhibits. It seems probable that some vital changes are produced in the fluid both of the lacteals and lymphatics, during its passage through their tubes; and the prolongation of these appears essential to their performance (see CHAP. VIII.).

334. In BIRDS we find the lymphatic system existing in a more perfect form, its trunks being provided with valves, and the diffused plexuses being replaced by glands or ganglia, which seem to be only another aspect of the same structure. These can scarcely be compared with the other organs designated by that name, since their function does not appear to consist in the separation of any products from the blood which passes through them. They consist of a number of convolutions of lymphatic trunks closely approximated to one another, through which veins also are dispersed. Although direct communicatons between these two systems of tubes have been alleged to exist in the lymphatic glands, the statement is probably erroneous; the passage of fluid from one to the other, which can be made to take place by forcible injections, being due either to a rupture of the coats of adjoining vessels, or to the transudation of fluid through those invisible pores which must exist wherever absorption is performed. It seems probable that in the lymphatic glands some mutual changes are effected between the blood and the lymph, through the walls of their respective vessels; but of the nature of these, we are entirely ignorant. Similar formations occur on the lacteal trunks; and they generally exhibit the same degree of complexity with those of the lymphatics. The absorbents of Birds terminate principally by two thoracic ducts, one on

each side, which enter the jugular veins by several orifices; there are, however, two other entrances, as in Reptiles, into the veins of the lower extremity. These are connected with two large dilatations of the lymphatic trunks, which are evidently analogous to the lymphatic hearts of reptiles, but which do not seem to have any power of spontaneous movement. In the Goose, they are about the shape and size of a kidney-bean, and are situated in the angle between the tail and the thigh. They were supposed by Panizza to possess an automatic power of alternate contraction and dilatation; but this motion has been shown by Müller to be due to the respiratory actions, being synchronous with them, and ceasing when they are interrupted.

335. In MAMMALIA, both lacteals and lymphatics terminate entirely in the *thoracic ducts*, of which that on the left side is usually the largest, the right trunk receiving only the lymphatics of the right side of the head and upper extremity, with those of the right lung and right side of the liver. These terminate at the angle formed by the junction of the subclavian and internal jugular veins, on the two sides respectively; and it is a beautiful instance of mechanical adaptation, that this should be a point of much less resistance to the entrance of a fresh current, than if the aperture had been made in the side of a single trunk. Although these are the only two canals by which the lymphatics usually communicate with the veins in man, their number is greater in many species of Mammalia, although they all terminate in the same part of the venous system. Thus, the left thoracic duct often resembles rather a plexus of vessels than a single tube, branches proceeding from it and then reuniting, and at last terminating in the veins by several apertures. Sometimes it consists throughout of two tubes, which anastomose with each other and with the duct on the right side, and terminate separately in the veins; and in the Pig a branch of communication is sent off to the vena azygos, which is a small trunk running in proximity with it along the spinal column. All these modes of distribution occur as irregularities of conformation in the human subject, the former not being uncommon; the last, however, is rare. In the lymphatic system of the Mammalia we witness its most concentrated and highly developed form; the vessels are copiously provided with valves; and their parietes are firmer than in the lower classes. Instead of the extensive plexuses of Fishes, we find small dense lymphatic glands disposed in different parts of the system; these are more numerous than in Birds, and are most abundant in the lymphatics connected with organs which may receive or imbibe substances from without, such as the digestive cavity, the lungs, and skin; whilst they are smaller and more scattered upon the absorbents which arise from deep-seated organs, the substance of the limbs, &c. It is somewhat curious that where two lymphatic vessels unite, the common trunk is frequently not larger than either of those which form it; and thus the large canals do

not exhibit by any means the same proportion to the primary branches of which they are composed, as the great veins or arteries to their capillaries.

336. The peculiar characters of the lymph, and the sources from which it is derived, will be considered in the next chapter. Although a part of it is certainly derived from the fluid portions of the blood which have transuded through the sides of the capillaries for the nutrition of the adjacent tissue, there appears little doubt that the lymphatics may, like the lacteals, take up fluid brought into relation to them from without. In fact, the cutaneous lymphatics are to the external surface what the lacteals are to that portion of it which is reflected inwards to bound the digestive cavity (§ 262); and it is a little remarkable that we find both sets of vessels developed at the same part of the animal scale, the functions of each having been previously performed by the general circulating system. That it is by means of the lymphatics, and not by the veins, that substances applied with friction to the skin are chiefly absorbed, appears evident from the circumstance that if these be of an irritating character, red streaks appear in the course of the lymphatics, and the neighbouring glands are swollen: their absorbent power is also evinced by the fact that the branches surrounding collections of peculiar animal fluids have been seen filled with those fluids; thus, when the bile-ducts have been obstructed, the lymphatics of the liver have been seen to contain fluid of a yellow colour which contained the components of bile. The absorbent power of the lymphatics of the skin is shown by an experiment of Schreger's. Having tied a bandage round the hind-leg of a puppy, the limb was kept for twenty-four hours in tepid milk; at the expiration of this period the lymphatics were found full of milk,—the veins contained none. In repeating this experiment upon a young man, no milk could be detected in the blood drawn from a vein. A striking experiment which led to the same conclusion is mentioned by Müller. He placed a frog with its posterior extremities entirely immersed in a solution of prussiate of potash, and kept it so for two hours. He then washed the animal carefully, and having wiped the legs dry, tested the lymph taken from under the skin with a persalt of iron; the lymph assumed immediately a bright blue colour, while the colour of the serum of the blood was scarcely perceptibly affected by the test. In a second experiment, in which the frog was kept only one hour in the solution, the salt could not be detected in the lymph.

337. There is doubt, however, that in many cases the veins participate in the function of absorption even more actively than the lymphatics. Thus, when a solution of prussiate of potash was injected into the lungs by Mayer, it was detected within five minutes in the serum of the blood, and long before it could be traced in the chyle; and it was found in the left side of the heart (to which the pulmonary veins appeared to have conveyed it) before a trace of it could be detected in the right cavities;

while, if the absorption had been effected by the lymphatics, the course of the lymph being first into the venous blood of the body, the salt absorbed ought to be first detectible in the right cavities of the heart. It has been also found that when the veins have been laid bare, and the poisonous substances have been applied to their exterior, their usual effects upon the system have followed. It might not perhaps be difficult to reconcile these apparently contradictory results, by attention to the predominance of each system of vessels in the part to which the absorbed substance has been applied. Thus, as already mentioned, the ramification of the lymphatics in and beneath the skin is most universal; whilst the very object of the lungs being to expose the blood to the air, its capillaries necessarily approximate more closely than the lymphatics to the absorbent surface, and will consequently be more directly affected by external agents. With regard to the last experiment it is to be recollected, that the impediment arising from the tissues in which the vessel was enveloped being removed, it might be expected that it should readily imbibe fluid through its thin parietes; and it can scarcely be deemed improbable that, if a lymphatic trunk of the same size existed in the body, it would absorb fluid applied to its surface with even greater rapidity.

338. But absorption takes place, not merely from the surface of the body or its cavities, but from the tissues themselves. One of the most evident examples of this process is the wasting of the body from the absorption of fat, which takes place during almost all diseases, and during hybernation. The removal of fluids which have been effused through the tissues, as in dropsical swellings, or of the colouring matter of the bile which has been deposited in jaundice, are instances in which this function tends to repair the effects of disease; but there are many cases in which its too great activity in itself constitutes disease, by causing a loss of substance which impairs the continuity of the tissue. There are other circumstances, again, in which interstitial absorption, taking place as one of the regular series of vital changes, without a corresponding deposition of nutritive materials, produces atrophy or wasting of an organ; but this is sometimes a natural condition, and effects those alterations in the relative proportions of different parts of the body which are so remarkable at progressive stages of growth. Thus are produced the disappearance of the tail of the tadpole, when it is metamorphosed into a frog; the removal of the membrane which closes the pupil in the fœtus; the formation of cells or even of large cavities in bones which were originally filled with medullary pulp; the wasting of the thymus gland from infancy to the twelfth year, and many other effects of the same kind.

339. It may still be doubted to what extent these phenomena are occasioned by the lymphatics, or how far the veins partake in their production. In bony tissue, lymphatics have never yet been demonstrated; still, however, their existence cannot be altogether denied, since cellular

tissue is the basis of the structure, and this is always permeated by absorbents. If they are really absent, the process of absorption, which is often very actively performed in the bones, is manifestly due to the veins. Their cells are developed in the child long after the bone is formed, and increase in size by the agency of the same process; some of these cells subsequently attain large dimensions, as those which form the frontal and sphenoidal sinuses, which are not developed until the period of youth; and in birds the long bones, which are at first filled with a spongy medulla, are afterwards completely hollowed, and brought into connection with the respiratory organs (§ 412). The roots of the first teeth are absorbed at the time they are shed; but this is perhaps due, not to interstitial absorption taking place in their own substance, but to the same kind of process as that by which the Mollusca are enabled to modify the form of their shells (§ 100). When atrophy is a general condition of the system, a certain order is usually observed in the wasting of the tissues; fat being absorbed first, then cellular tissue, and then muscle, bone, cartilage, and tendon. Various artificial agents may produce the same effect with disease; thus, long continued pressure, by putting a stop to nutrition, may cause every tissue to be absorbed. Iodine, on the other hand, whilst it probably impairs the nutritive functions, stimulates the absorbent processes themselves, and hence is advantageously employed for the removal of indolent tumours, especially those connected with the lymphatic glands.

340. Of the causes of the motion of the fluid contained in the lymphatic trunks in those higher animals which are unprovided with propelling cavities, little satisfactory explanation can be given. It is probably due in part to the force created by absorption at their origins, like the ascent of the crude sap in the stems of plants; and it may be assisted by the occasional pressure resulting from muscular action on the trunks, which will force their contents in the direction permitted by the valves. But these explanations, as well as all others which have yet been offered, are insufficient to account for the fact that if a ligature be put on the thoracic duct, the lower part will be distended even to bursting.

CHAPTER VIII.

NUTRITION AND FORMATION OF TISSUES.

General Considerations.

341. The nature of the absorption of alimentary fluid, and the means of its transmission, when required, to distant parts of the system, having now been considered, the question next arises how the nutritive ingredients thus introdueed are applied to the development and maintenance of the several portions of the structure. The conversion of the inorganic elements which constitute the food of Vegetables, into tissues of complex formation, and possessed of qualities entirely different from those of their components, is a process in which several stages may be traced with considerable distinctness; and although the aliment intoduced into the Animal system never exists in a state of corresponding simplicity, yet the alteration which it undergoes in composition and properties are scarcely inferior in extent or peculiarity of character. With regard to the nature of these changes, our knowledge is very limited; it is derived principally from the study of their most evident effects; but there can be little doubt that the imperfection of our present means of observation has caused, and will continue to produce, great ignorance of what may be in reality their most important particulars.*

342. In cases in which the processes of nutrition are *manifestly* of a complex nature, and where the conversion of the alimentary materials into organised tissues does not so immediately follow their absorption as in the simplest forms both of the animal and vegetable kingdoms, a considerable alteration may be traced in the character of the nutritious fluid between the time of its first reeeption into the system and its application to its ultimate purpose. This alteration consists in the formation of certain new combinations of its elements, into substances ready to be *assimilated* by the various tissues,—that is, to be converted by organisation into part of their own structure. It is probable that even in beings whose simplicity of conformation prevents us from discerning any change intervening between the absorption of aliment and the growth and renovation of the tissues, the same process really takes place; as it would seem to be a general law of organisation that no solid textures can assimilate, or convert into living structures like their own, matter which

* Thus, the recent application of polarised light to the examination of vegetable juices, has shown that during the progress of vegetation, important differences may be detected in the nutritious principles, which were not previously supposed to exist; that it is not improbable that its more extended employment may have a powerful influence in disclosing to us some of the most recondite processes of Nature's laboratory. See Taylor's Scientific Memoirs, vol. i. p. 584, *et seq.*

has not been previously formed into combinations differing essentially from those which exist in the inorganic world. Thus, we find in the blood a variety of ingredients, most of them peculiar to animal bodies, which have been produced subsequently to the first reception of its materials into the digestive cavity, and which are prepared for the reparation and maintenance of the several tissues; and, in like manner, the elaborated sap of vegetables contains other principles peculiar to th vegetable structure and adapted to its maintenance. These are called, therefore, *organisable products;* and are partly identical with the substances denominated by the chemist, *proximate principles:* amongst the latter, however, are found many which do not furnish materials for organisation, but are rather its results,—being the constituents of the various secretions, which are either carried out of the system altogether, or stored up within it for particular purposes.

343. Of the means by which the simple ingredients that enter the absorbent system are converted into organisable products, little is positively known; but the result of late chemical researches certainly favours the idea that the affinities by which their elements are held together are not different from those which operate in the production and changes of the combinations presented to us in the inorganic world; and that, being subject to the same laws, they may be made to exhibit analogous phenomena. In forming an opinion on this subject, it is necessary to keep in view that the conversion of organisable products into *organised tissues* is a process entirely different from the production of the former, and takes place under the laws of vitality alone. In fact, the power of communicating to nutritious matter their own structure and properties, which is the most obvious characteristic of living beings in general, is also peculiar to each of their component textures. Thus, from the same circulating fluid of uniform character in every part of the body, is developed in one spot muscular fibre, in another nervous tissue, in another solid osseous matter, and so on; the new matter, in every instance, being deposited in continuity with the previously-existing structure. An organised character is not, however, peculiar to living solids; for some traces of it may be detected in the circulating fluid, which is also possessed of properties that must be considered as *vital*, since they differ from any which a mere mechanical admixture of the ingredients could present. Thus, the phenomena of the coagulation of the blood cannot be satisfactorily explained without this admission; and those exhibited by the descending or elaborated sap of vegetables seem to place it in the same light (§ 346). It would seem, then, that the solid parts, which most unequivocally exhibit this peculiar character, not only obtain from the nutritive fluid the materials necessary for the reparation and extension of their structure, to which they communicate their vital properties,—but, in absorbing aliment from without, and converting it into forms most adapted to their mainte-

nance, also endow it, whilst still fluid, with qualities which prepare it for its final assimilation. In tracing the alterations which occur in the alimentary fluid, from the time of its first absorption to its ultimate destination, we have therefore not only to enquire into the changes in the chemical relations of its constituents, but into the traces of organised structure and vital properties which it manifests. It is obvious that these changes can be more distinctly studied in proportion as their different steps are separated from one another; and accordingly it will be desirable to examine them first as they occur in the higher classes of plants and animals, and then to apply the results thus obtained to those of more simple conformation.

Nutrition in Plants.

344. In the usual condition of most Vascular plants, there is no doubt that the greatest proportion of the fluid imbibed into the system is derived from the soil surrounding the roots; and that it holds in solution carbon in various forms, which is ultimately to enter into new combinations with the other elements, for the production of the organisable products, gum, sugar, &c. which are the principal sources of the maintenance of the tissues. It would seem that the fluid thus absorbed is in all plants nearly the same under corresponding circumstances; though of the mineral ingredients of any soil, some will be selected most abundantly by one plant, some by another. The sap in ascending the stem soon, however, undergoes an alteration, by dissolving the secretions which had been laid up from the previous year; and this admixture, whilst it furnishes a necessary condition for the continuance of the absorption, may also not improbably be an important aid to the process of conversion of the crude materials which is taking place at the same time. The ascending sap, when examined sufficiently near to the roots, is almost uniformly found to be of very low density, and to possess no characteristic properties in different orders of plants. In its upward ascent, however, its specific gravity increases, from the cause just mentioned; and the quantity of sugar and gum contained in it is sensibly greater. How far these are newly-formed products, or are merely dissolved by the fluid in its passage through the stem, it is not easy to say. It is probable, however, that the greatest addition made to the solid tissues of vegetables is effected by the absorption of carbon from the atmosphere by the surface of the leaves; and the real process of the conversion of the oxygen, hydrogen, and carbon thus obtained from the surrounding elements, into organisable products, cannot be said to take place until the crude sap arrives there.

345. The crude sap brought to the leaves consists of little more than water; a very abundant absorption of which is necessary to introduce into the system a sufficient quantity of the mineral and other ingredients which are so sparingly diffused through it. The separation of a large

proportion of fluid by the process of exhalation is, therefore, one of the principal changes required for the concentration of its nutritious contents; and it will be subsequently shown (§ 431) that the quantity retained in the system frequently bears a most inconsiderable relation to that originally received into it. A plant in active vegetation and exposed to the influence of solar light, obtains a considerable supply of carbon from the atmosphere, by means subsequently described (§ 373), and thus is capable of adding to the amount of its organisable materials; for these consist of little else than carbon united with the elements of water in varying proportions. The sap elaborated by these processes has undergone a very evident change in its character; for instead of being a thin watery liquid nearly the same in all plants, it is dense and viscid, and contains not only the materials necessary for the nutrition and the formation of the different parts, but the products characteristic of each order which constitute its peculiar secretions. It is well known that the juices expressed from the leaves always contain these principles, although sometimes in a diluted form, a particular part of the structure being frequently adapted to separate and store them up. The crude sap may afford a refreshing beverage, whilst rising in abundance, although that which is descending after elaboration cannot be tasted with impunity. Thus, the inhabitants of the Canary islands tap the trunk of the *Euphorbia canariensis*, and draw off the ascending current for this purpose, although the proper juice of the plant is of a very acrid character.

346. In the ascending sap there is but little trace of organisation, nor does the fluid exhibit any properties which can be regarded as vital. Some traces of globules have been observed high up in the stem; but these may have been derived from the previously assimilated matter. In the descending sap, or proper juice, on the other hand, globules are very abundant; and they may be seen to move not only within the canals of the living plant, but even when the fluid is drawn from it. According to the observation of Amici* the glutinous sap of the vine when removed from the stem assumes, during the species of coagulation which it undergoes, regular forms, closely analogous to those of the lower Confervæ on the one hand, and to the elementary tissues of which it supplies the materials, on the other. When wounds have been made in the course of its flow, it is evidently from the exudation which takes place at their edges that the regeneration of substance takes place; and it scarcely admits of a doubt, therefore, that the ingredients it contains are not *mere* chemical combinations of elementary bodies into organisable products, but that they are to a certain extent possessed of vital properties, which have been probably communicated to them simultaneously with the traces of organisation they exhibit. The proper juice, then, seems to contain the materials of the solid parts which compose the structure of the

* Annales des Sciences Naturelles, tom. xxi.

plant, as well as of its various secretions and excretions: the former existing to a certain extent in the crude sap, and being but little prone to spontaneous decomposition; the latter appearing to be compounds of a higher order, being more removed from inorganic substances in form and composition, and in general more liable to the separation of their elements. The gum and sugar contained in the crude sap, with the additional carbon derived by the leaves from the atmosphere, would seem to be readily convertible into the materials essential to the growth of the plant, and these are formed under almost any circumstances which permit the maintenance of its existence; but it requires a perfect state of the vegetative powers, and the presence of the necessary external stimuli in a high degree, to produce some of those peculiar secretions of which such a remarkable variety exists in the vegetable kingdom.

347. The organisable product most universally existing in the proper juices of plants, is *Gum*. It is found in the bark and wood of all trees, and is present in such abundance in several as to flow from the bark when wounded, or when its surface cracks; this exudation is, therefore, to be considered in the light of an accidental hemorrhage, and not of a regular excretion. The following reasons may be specified for regarding gum as the essential ingredient in the nutritious fluid. 1. It exists in all vascular plants without any known exception. 2. It is found in all their organs, particularly in the bark where some of the special secretions appear to be formed. 3. Its properties seem favourable to the life of plants, which grow readily in a solution of it, if not too viscid. 4. Its composition, which is merely carbon in union with water, is such as might be expected from the action of the leaves upon the crude sap. 5. This composition differs little from that of the substances which form the basis of the organised textures; and these substances are convertible into gum by simple chemical processes.—Various modifications of this principle exist in different vegetables; but they may all be considered as combinations of pure gum with other principles.

348. *Sugar* is considered by Dr. Prout as being, from its crystalline form and simple constitution, the most allied of any of the organic products to inorganic combinations. Several varieties of it may be obtained from different sources; that of the cane, which seems the purest, and which may probably be regarded as the type of the rest, is composed, according to Dr. Prout, of 9 atoms of carbon and 8 of water. The sugar of honey contains 9 atoms of carbon and 12 of water, and may thus be regarded as a compound of water and pure sugar, or a hydrate of sugar; other forms of this principle, differing somewhat in their sensible properties, might probably be represented in the same manner. There are some instances in which sugar appears to be the first organic compound formed by the combination of the external elements, as when abundantly existing in the ascending sap of trees,—the maple, for example; frequently, how-

ever, its formation is the result of other processes, as when it is produced by the conversion of starch in the manner to be presently mentioned. It appears to be the form of nutriment best adapted for the development of rapidly-growing succulent parts, (thus the sugar in the stem of the cane is exhausted by flowering, and that which is so abundantly contained in the cortical system of the beet, is ultimately carried into the upper part of the plant, and similarly diminished by its inflorescence); and whenever a store of nutriment has been previously laid up for their maintenance, it is made to assume the form of sugar before being applied to its destined purpose.

349. Neither of these principles ever exhibit traces of organisation, and they may therefore be regarded as strictly *organisable* products; but there is a peculiar form of the first, which appears in some respects intermediate between its usual condition and that of the living tissues which are formed from it. This is *Fecula* or *starch*, a principle very universally diffused through the vegetable kingdom. Starch, when removed from the plant, exists in the form of minute granules, each of which, if examined with the microscope, is found to consist of a little vesicle, having an insoluble envelope formed of a kind of organised membrane, and containing within it a substance very analogous to gum. These grains resist the actions of many chemical agents; but when exposed to a heat of about 160°, the pellicle bursts, and its contents are liberated; and this is the explanation of the fact that starch once dissolved in hot water can never be restored to its original form. Fecula may in fact be considered as little else than gum divided into minute portions, each of which is enclosed in a membranous cell; and in this state it appears to answer very important ends in the vegetable economy. It is remarked by De Candolle that "while gum itself may be considered the nutrient principle of vegetation, diffused freely through the structure of the plant, and constantly in action, starch is apparently the same substance stored up in such a manner as not to be readily soluble in the circulating fluids," thus forming a reservoir of nutritious matter, which is to be consumed—like the fat of animals (which it closely resembles in structure)—in supporting the plant at particular periods. Thus, we find it stored up in the *seeds* of most species, either forming a separate albumen as in the Grasses, or taken into the structure of the embryo and constituting the mass of the fleshy cotyledons, as in the Leguminosæ, &c. (§ 49, 50); in each of these cases it serves as a magazine of food for the nutrition of the embryo, until the development of those organs which enable it to maintain an independent existence. Similar reservoirs are occasionally formed by the enlargement of the *stem* into tubers, for the nutrition of the buds to be developed from them,—as in the Potatoe, Arrowroot plant, &c.; or by the accumulation of the same material in fleshy *roots*, *bulbs*, &c., from which stems rapidly grow up. Fecula is also found abundantly in the soft interior (improperly called pith) of the stem of the Sago Palm and other Endogens, where it seems

destined to assist the evolution of the young leaves; and in the fleshy expansions of the flower-stalk (termed *receptacles*), on which, in many orders, the flower is situated, and in which it seems to answer a corresponding purpose.

350. In all these cases, the immediate end of the accumulation of fecula is that it may be ready for the nutrition of the young germ before it is capable of obtaining food for itself; and it may be observed that the deposit continues to increase as long as the plant is in active vegetation,—arrives at its maximum,—and then, remaining stationary during the winter, begins to decrease in the spring. The deposition of fecula fulfils, therefore, an obvious purpose in the Vegetable economy; but we cannot doubt the wise and benevolent intention of the Creator, in thus providing a store of nutritious and palatable food for man in situations whence he can so easily obtain it; and it is interesting to remark that, as it almost always exists in an insulated form, it may be obtained in a state of purity from many vegetables which would otherwise be very poisonous. Before it can be applied to the nutrition of the plant, however, its condition must be changed. Thus, in the germination of seeds, it is converted into sugar, which is the form of aliment best adapted to the development of the embryo; the same change takes place in the tuber of the potatoe; and, from the researches of Dunal (§ 381), it seems probable that the starch deposited in the receptacle is converted during the period of flowering into sugar. This conversion is a process which the chemist can imitate; for if the fecula be first heated, so that its vesicles may be ruptured, and then treated with dilute sulphuric acid, it is converted into sugar. This change is effected in the vegetable economy by the operation of a secretion called *diastase*, which seems to be formed for the express purpose, and may be obtained in a separate state most readily from the neighbourhood of the *eyes* or *buds* of the potatoe. It is stored up in that situation for the purpose of being conveyed, by the vessels connected with the bud, into the substance of the tuber, when the demand for nutrition is occasioned by the development of the shoot; and, in the laboratory of the experimenter, it produces exactly the same effects as in the vegetable economy. It is probable that the secretion of diastase takes place in every instance in which fecula previously deposited is to be reabsorbed.

351. *Lignin* appears to be a modification of gum which constitutes the basis of the solid tissues of plants, and never exists but in an organised state; it must, therefore, be considered as taking a higher rank than the substances previously described. It may be converted into a substance resembling gum by admixture with strong sulphuric acid; and, on boiling the liquid for some time, the gum disappears, and a saccharine principle is generated. Much diversity has existed in the statements of different chemists as to its elementary composition, probably arising in part from

the deposition of other secretions within its cavities. According to the statements of Dr. Prout, it consists of 9 atoms of carbon to 6 of water; and it differs from gum, therefore, in containing a larger proportion of carbon. This fact accounts for the influence of light upon the density of wood; since, as will be subsequently mentioned (§ 373), it is under that stimulus alone that the fixation of carbon from the atmosphere can take place.*

352. The mode in which the organisable products are converted into living tissues must ever remain a matter of great obscurity. Some curious facts are known, however, of which a summary may be advantageously given. It has been already stated (§ 22) that all the vegetable tissues may be regarded as taking their origin from the cellular, since this appears to be the only one existing in the germs and first-formed structures even of the most highly-organised plants. Although at a late period, therefore, it would seem to be a general law that each tissue is developed in connection with one similar to it, this does not prevent textures apparently heterogeneous from being evolved from those which were previously simple and uniform, since they are all but modifications of one another.

353. For the development of cellular tissue to any extent, a single original vesicle seems all that is required. A most remarkable instance of its rapid growth has already been mentioned (§ 231); and although amongst flowering plants there is not the same proportional multiplication of cells, yet their number is often very quickly increased. Thus, the leaf of the *Urania speciosa* (one of the Banana tribe) has been known to lengthen four or five inches in one day, the vesicles being developed at the rate of about 4000 or 5000 per hour. The evolution of new cells at the extremities of those previously existing may be easily watched in the *Chara* tribe, where they are arranged in single rows so as to constitute the tubular filaments of which those plants are composed. In expanded membranes formed of aggregated rows of cells, the new vesicles seem to be interposed between the old ones. This appears from the observations of Mirbel on the extension of the beautiful little fringe which surrounds the mouth of the urn containing the gemmules or buds of the *Marchantia polymorpha* (§ 61).† The circulation of fluid which has been observed in

* Hence it is that wood, not only of different kinds of trees, but of different individuals of the same species, differs so much in density. It is well known that for toughness and durability, the stems which have grown in exposed situations, though stunted and irregular, are much superior to those which have been luxuriantly developed in close and shady woods. Homer tells us that the heroes of old used to cut the wood for their spears from trees growing in exposed situations; and a recent traveller in Holland mentions that the beeches growing in thick groves, so close together as to exclude every ray of the sun, as well as to impede the action of the atmosphere, are good for nothing but fire-wood, the trunks riving and splitting in every direction, when brought out of the forest.

† Nouv. Ann. du Musée. Tom. I.

the separate cells of the *Characeæ*, as well as in other plants, seems undoubtedly connected, not only with the nutrition of the individual vesicle, but with the development of that which is taking its origin from it. Each joint (Fig. 55) consists of a single cell composed of a membranous envelope, within which is arranged a layer of green granules covering every part, except two longitudinal lines which remain nearly colourless. During the healthy state of the plant, a constant motion of the semi-fluid matter, containing numerous jelly-like globules, is seen to take place within this green layer; the current passing up one side, changing its direction at the extremity, and flowing down the other,—the ascending and descending streams being bounded by the transparent lines just mentioned. These lines appear to result from the adhesion, at those points, of an internal membranous sac to the outer envelope; and the space between the inner and outer vesicle will thus be divided into two cavities, which communicate with each other at the ends of the cell. An imaginary transverse section of one of these tubes (Fig. 55, A) will illustrate this curious structure; *a*, *a*, being the outer envelope, *b*, *b*, the layer of green granules, *c*, *c*, the internal sac adhering to the outer one at *d*, *d*, and leaving the spaces *e*, *e*, within which the fluid circulates. The globules are of various sizes, being sometimes very small and of definite figure, and sometimes existing as large irregular masses which appear to be formed by a union of smaller ones. There is little doubt that the layer of granules is formed by the adhesion of some of the circulating globules to the outer membrane and to each other, since they are always found to correspond closely in size. Thus, at B are seen the globules floating in their fluid, and at C is shown their regular disposition when lining the cell. It scarcely seems unlikely that during their circulation they undergo those changes which take place on a larger scale in the ingredients of the general circulating fluid of vascular plants, becoming gradually organised by their relation with the living structure which envelopes them; and that the green layer is the intermediate condition between the first formation of organisable products and their conversion into the actual tissue of the cell. No passage of fluid from one cell to another ever seems to take place; and if a long tubular vesicle be divided by a ligature, a separate movement is seen in each of the divisions. The globules effused from a cut cell have themselves a spontaneous motion.

354. Although this circulation has been most attentively watched in the plants of the Chara tribe, in which the cells are so large as to exhibit it in a very evident manner, it is by no means confined to them, since it has been observed in the individual vesicles forming the hairs and other transparent parts of higher plants; and it might probably be detected at some period of the growth of every vesicle whose situation permits it to be watched, since it seems closely connected with the nutrition of the individual cell, and the production of new ones from it. Thus, the transparent

scales at the foot of the leaf-stalks of the *Hydrocharis morsus-ranæ* or frog-bit, a common aquatic plant, exhibit precisely analogous phenomena in their individual cells, though the presence of an internal membrane is not quite so evident; and the same may be observed in a section of its stem,—the motion being for a time checked by the violence, but soon recovering itself in the cells which have not been injured, if the portion be immersed in water. In the beaded hairs of the *Tradescantia virginica* or Virginian spider-wort, a similar circulation may be easily witnessed; as well as in the elongated cells which sometimes singly form hairs, as in the *Penstemon;* and in the transparent radical fibres of Marchantia, Mosses, &c. This movement of fluid in the individual cells must not be confounded with the general circulation of the plant, as it is perfectly distinct both from the ascent of the sap in the vessels of the stem, and from the distribution of the elaborated fluids by their passage through their special canals as already described (CHAP. VI.). Where each cell elaborates its own nutriment, as in the Chara, it is more distinct, and probably takes place with greater energy, than in those which are supplied with fluid that has already been partly assimilated. Little granules are seen adherent to the walls of most vesicles of cellular tissue; and when the membrane is ruptured by violence, and they are effused into water, they are seen to have a spontaneous motion like that of the globules of the Chara. To what this motion is owing, it is as yet impossible to determine; but similar phenomena will be shown to occur in regard to the animal fluids (§ 363).

355. The details just given of the mode of increase observed in the development of cellular tissue, express nearly all that is certainly known of the processes of nutrition in the lower Cryptogamia. It may be added, however, that many Fungi exhibit a circular growth in concentric rings, owing to the exhaustion of the nutriment from the soil on which they vegetate, and the consequent death of the central first-formed portions, whilst the edges continue to extend over new spaces. This is the method in which *fairy rings* are produced. It is generally found that when the vesicles are regular in shape, their increase takes place equally in all directions; whilst, if they be of a prolonged form, the new cells are developed from their extremities. This is equally true of the cellular tissue of vascular plants; for whilst that which is mixed with the wood and forms a large part of the bark has a tendency to lengthen vertically, those of which the medullary rays are composed are necessarily extended in a horizontal direction, to maintain that communication between the centre and circumference of the stem which would otherwise be cut off by its increase in diameter. As to the mode in which woody fibre is formed, there is a considerable difference of opinion amongst vegetable physiologists. Between the last layers of wood and bark in Exogens there is formed every year from the descending sap a glutinous secretion,

termed the *cambium*, which exhibits traces of incipient cellular organisation. After a time, parallel rows of woody fibre are found in this situation, intermixed with cellular tissue; and these subsequently divide into two distinct layers, of which one forms the outer ring of alburnum, whilst the other constitutes the interior lamina of the bark enveloping it. These remain in contact until the new formation of cambium in the succeeding year. It is the opinion of many physiologists that the woody fibre, as well as the cellular tissue, is formed out of the cambium; but there are many reasons which seem to render this opinion untenable. The most consistent account of its development is that given by Du Petit Thouars, who, followed by Lindley, regards the fibrous tissue as formed in the leaves and growing downwards from them into the cambium, just as the roots are prolonged into the soil. This view would liken the woody fibres to the roots of the buds; and such a comparison, though at first sight improbable, is fully borne out by facts of no unfrequent occurrence. Thus, it often happens that a stem dies, whilst some of the buds upon it continue to vegetate, and send down woody bundles in the usual situation, which, after reaching the ground, form true roots. A graft, even, has thus maintained its existence after the death of the stock, completely enveloping the latter in the wood it has formed. Again, in Endogens, where there is no bark or cambium, the woody fibres may be traced from the leaves into the centre of the stem. It is difficult, therefore, to resist the conclusion that this tissue is organised in the leaves, although it may derive the means of increase from the nutritious juices which it traverses in its descent. It is, then, from the growth of this structure that the roots are developed, and the longitudinal increase given to the stem; whilst the cellular portion of the stem, from which the buds take their origin, is capable of extension in any direction, and of thus accommodating itself to the distribution of the woody bundles.

Nutrition in Animals.

356. In tracing the gradual conversion of the alimentary materials ingested by Animals, into the organised structures which compose their fabric, it is advantageous, as in the case of Vegetables, to study in the first instance the cases in which the different changes are most widely separated from each other. The most attentive observation of the life of the Sponge would probably never reveal much more than is at present known respecting the nutrition and growth of its tissues; whilst, on the other hand, the function which there appears so simple is shown, when we turn to the higher classes of animals, to be one in which several distinct stages may be traced. The general facts relating to the solution and reduction of the food by the process of *digestion* have been already stated (§ 257—262); but it is now to be enquired what is the precise change effected in its constituent parts, and what new products are found

in the *chyme* which is the result of these actions. Although the chyme is usually homogeneous, and exhibits little or no trace of the character of the food which has been swallowed (unless it contain absolutely insoluble matter), it is not identically the same whatever be the nature of the aliment, as some have maintained. The characteristic ingredient of it is always, however, the *proximate principle* (§ 19), or *organisable product* (§ 342), termed *Albumen.* This appears to hold the same place in the Animal economy with gum in the Vegetable; being the material at the expense of which most, if not all, of the other products are formed. It is that which is stored up in the egg by the parent, for the nutrition of the embryo,—composing a large part of the *yolk*, and existing nearly pure in the *white*, which, therefore, affords us an opportunity of studying its properties. It appears to consist of 8 eq. of carbon, 7 eq. of hydrogen, 3 eq. of oxygen, and 1 eq. of nitrogen; and it may be probably regarded as the least azotised of the materials of the animal tissues. Its characteristic property is that of *coagulating* by heat, acids, electricity, &c. A temperature of about 150° converts the transparent, semi-fluid mass, into a firm white, semi-opake, and somewhat elastic substance, which, when cautiously dried, shrinks up and assumes the appearance of horn. In its fluid condition, albumen is soluble in water, if combined, as it always is in nature, with a small quantity of soda; but after coagulation it no longer possesses this property, so that a turbidity is produced by heat in a solution containing only a thousandth part of albumen. A substance much resembling it, both in chemical constitution and the power of coagulation, is found in some vegetables, especially in seeds. But the albumen of chyme doest not exist in precisely the same condition; since white-of-egg, taken into the stomach, is found to undergo important changes in the process of digestion. It is first coagulated by the action of the gastric juice, of which the acid appears to be the essential ingredient in this process. The curdy mass assumes a gelatinous appearance; and, by the combination of the mechanical and chemical powers of the stomach, it is gradually converted into a fluid which subsequently becomes chyme. Although still existing as albumen, it is now incapable of coagulating firmly, and thus differs essentially from that which is met with elsewhere. According to Dr. Prout, all the materials which serve as aliment to animals, are converted by the digestive process into compounds of an *albuminous* or an *oleaginous* nature. The former is always present in the contents of the stomach, when the food has been composed of similar elements; but if it have been of a vegetable character, the albumen more resembles that found in plants than the true animal principle. After the products of digestion have been submitted to the action of the bile and pancreatic fluid, however, true albumen is always distinctly present. Many forms of vegetable aliment, which are composed of substances allied to sugar in their composition (hence termed by Dr.

Prout the saccharine group), appear to be converted during digestion into an oily matter, which is a constant ingredient of chyle, but which seems to be partly changed, before entering the general current of the circulation, into other principles. Although albumen, in its uncoagulated state, is perfectly homogeneous, globules are found in the neighbourhood of the positive pole when it is being coagulated by electricity, and a similar character may be traced in white-of-egg, when dried in a thin layer, as well as in other albuminous fluids. It is not surprising, therefore, that globules should exist abundantly in the fluid part of the chyme; and their presence can scarcely be regarded as a proof of the *vitalising* powers of the stomach, since it may be doubted whether albumen can exist *pure* (that is, uncombined with the alkali which ordinarily keeps it in solution,) under any other form. The globules of the blood are quite distinct from these, possessing a definite *structure*, as well as peculiar vital properties.

357. The change which the chyme undergoes in the *duodenum* (the first portion of the intestine leading from the stomach) appears principally due to the admixture of the secretions there poured into it, whose effect has been already described (§ 262). The milky fluid which is thus separated and taken up by the absorbents, is termed *chyle;* and it differs in many important particulars from the first product of digestion. These differences, however, become more decided in proportion to the part of its course in which we examine it;—the properties of the fluid drawn from the lacteals near their origin being allied to those of the contents of the duodenum;—whilst the characters of the chyme drawn from the thoracic duct more resemble those of the blood. This change is evidently analogous to that which has been already noticed (§ 344) as occurring in the ascending sap of vegetables. The chemical constitution of the chyle, as well as its degree of turbidity, depend in part upon the character of the food; the latter being principally due to the admixture of oily fluids with the albuminous matter which may be regarded as its essential constituent. The chyle formed from animal food is usually most opake (containing a large quantity of fatty matter), and passes most rapidly into decomposition. That formed by herbivorous animals is more transparent, and frequently quite clear. The milky character is sometimes communicated to the serum of the blood, especially if the food contain much oleaginous matter, and the chyle be, from any cause, rapidly propelled into the current of the circulation. The oily particles, being suspended in the fluid in a state of minute division, cause it to present a globuliferous appearance; but, besides these particles, other globules may be observed in it, to which the turbidity (according to the observations of Müller) is partly owing. These globules are usually pretty regular in form, but of variable size; generally, however, they are about half or one-third the diameter of the red particles of the blood. It

can scarcely be supposed that these are identical with the globules which have been stated to exist in the chyme; since the vessels which take them up must terminate in pores of a sensible diameter, which all observers now agree not to be the case. It has been argued, however, that, as the blood of kittens and of puppies, if drawn at a certain time after sucking, exhibits turbidity of the serum on coagulating, the globules of milk must have entered the absorbents; but this argument becomes groundless when it is remembered that oleaginous food will produce the same effect in all cases.

358. Two hypotheses have been offered to account for the presence of globules in the chyle. According to one (that of Doellinger), the villi of the mucous membrane of the alimentary canal (§ 262) are constantly undergoing solution, where permeated by absorbent vessels, and are reproduced on their intestinal surface by the aggregation of the nutritive materials in contact with them. The immediate variation in the character of the chyle according to that of the food is, however, an evident objection to this doctrine; and, moreover, it is scarcely to be believed that the nutrient materials should be made to form part of an organised tissue (that of the villi), only to be again disintegrated. According to the other hypothesis, the globules are formed in the lacteals themselves, by a vital influence of the tissue of these vessels upon their contents. If this be the case, such influence must be exercised immediately as absorption has taken place; since globules may be found in the network of lacteals which is distributed on the surface of the intestines themselves. There is nothing discordant, however, in such a supposition, with what we observe elsewhere; for no other account than this can be given of the formation of red particles of the blood, which will be shown to have a comparatively elaborate structure. It is not improbable that a more attentive observation of the process of absorption in plants, and of the size of the particles of colouring matter which will pass through the spongioles, might elucidate this curious question.

359. It is in its power of spontaneous coagulation, however, and in the colour which it presents, that the peculiarities of chyle, in the later part of its course, are chiefly manifested. This coagulation will not take place in chyle taken from the smaller lacteals, and it rarely occurs even in that which has passed through the mesenteric glands (§ 335); but that which is drawn from the thoracic duct separates, in about ten minutes, into a coagulum, which consists of the globules connected by a transparent substance (probably fibrin),—and a serous fluid, containing from 3 to 5 per cent. of solid matter (chiefly albumen). The presence of the fibrin has been variously accounted for. It may either result from the gradual conversion of the albumen of the chyle, effected by some unknown action of the lacteal vessels themselves; or it may be produced by an actual admixture of some of the constituents of the blood, by their permeation of the coats

of the capillaries, which are in immediate relation with the lacteal tubes in the so-called mesenteric glands. But these glands are nothing more than prolongations of the lacteal tubes, on the walls of which blood-vessels ramify; and it seems the more probable supposition, that the presence of fibrin in the chyle results from the elaboration of the albumen previously contained in it, by processes of whose nature little is known, but whose conditions are open to investigation.* Fibrin would seem, as will be presently stated, to be a more highly-organised form of albumen, and to possess the capability of exhibiting actions of a character otherwise than physical. The red colour of the coagulum of chyle taken from the thoracic duct, is another indication of the approach of that fluid to the qualities of the blood. This becomes more evident after the coagulum has been for a short time exposed to the air; and it is much more perceptible in chyle taken from the summit of the thoracic duct than in that which is derived from its lower extremity. It is possible, however, that there is not an actual formation of red particles in the chyle during its ascent, but that these are derived from the spleen; since the lymphatics coming from this viscus are sometimes charged with fluid of a red-wine colour. Still it appears by no means unconformable to what we have elsewhere observed, to suppose that the presence of fibrin and of red colouring matter in the chyle are indications of the process of assimilation which is gradually being effected in it.

360. This admixture of *lymph*, the fluid taken up by the absorbents of the system at large, with the chyle in the thoracic duct, is a point which must not be forgotten in any account of the properties of the latter. This fluid is usually quite transparent, and contains no fatty matter. A delicate coagulum forms in it within about 10 minutes after its removal from the body, and this appears to consist almost entirely of the fibrin which was previously fluid,—a few small globules being inclosed in it; but the larger proportion of these remains suspended in the serous fluid, which contains a considerable proportion of albumen. The quantity of coagulum is very small, being, when first formed, not much more than $\frac{1}{100}$ of the weight of the fluid; and being reduced by drying to $\frac{1}{300}$. When dry, the coagulum presents a fibrous appearance. The globules are much smaller than the colouring particles of the blood, and are by no means abundant. In the frog, they are not above $\frac{1}{4}$ of the size of the blood-globules. It will be presently seen that the lymph is nearly identical in composition with the fluid portion of the blood; and it is not

* That the walls of vessels have some unknown influence on their fluid contents, which can only be regarded as of a vital character, appears from the following experiment amongst others. If two ligatures be placed round a blood-vessel, at the distance of two or three inches, the blood between them, although of course removed from the current of the circulation, will not coagulate for some time; but, if it be drawn from its receptacle, it undergoes the ordinary changes.

improbable that its principal source is from the separation of this portion (the *liquor sanguinis* § 364) in the capillary circulation, a larger quantity permeating the tissues than is required for the purposes of nutrition, and the superabundant part being taken up, along with other matters, by the lymphatics. It may also be presumed that the admixture of this highly elaborated fluid with the crude matter of the chyle has an important effect in assimilating the latter, and in preparing it to enter the general current of the circulation,—just like the admixture of the previously-formed secretions of plants with their ascending sap (§ 252).

361. In what the precise difference consists between *Fibrin* and albumen, it is not easy to say. The most obvious character of the former is its tendency to spontaneous coagulation, which can scarcely be regarded as otherwise than a vital property; and it will be seen that this frequently serves a most important purpose in the nutritive processes (§ 364). Fibrin may be most readily obtained in a pure state by stirring fresh-drawn blood with a stick, so as to prevent its coagulation in the usual manner; a fibrous mass will be gradually collected, which may be freed by washing from the red particles mixed with it, and consists of fibrin nearly pure. This substance is regarded as composed of 6 eq. of carbon, 5 eq. of hydrogen, 2 eq. of oxygen, and 1 eq. of nitrogen; on comparing these proportions with those of the elements of albumen, it will be seen that the nitrogen remains the same, whilst the relative quantity of the other constituents is diminished, so that this principle may be regarded as more highly azotised than the other. Its peculiarly animal character is manifested also in its tendency to pass rapidly into decomposition. After coagulation, it is entirely insoluble in water at common temperatures; but a very minute proportion is dissolved by the long-continued action of boiling water. Many attempts have been made to show the identity of fibrin and albumen; but however similar these principles may be in ultimate composition, there can be little doubt that they hold a very different relation to each other in the animal economy. Fibrin enters largely into the constitution of the muscles; but it is not easy to obtain it from them, since it is intimately mixed with the elements of cellular and vascular tissue. It is a fact of some interest in relation to subsequent enquiries (§ 503) that the fibrin of muscles, when triturated, becomes so strongly electric, that its particles repel each other and adhere to the mortar. Phenomena will be presently mentioned which render it probable that certain vital endowments possessed by the fibrin of muscles exist also in that of the blood.

362. In proportion to the perfection of organisation which the alimentary materials are ultimately to attain, appears the degree of elaboration which they require. It has been already stated (§ 262) that, in the INVERTEBRATA, the absorbed fluid at once enters the general current of the circulation; but the blood of many of these tribes may be compared

rather with the lymph than with the blood of higher animals, having but few globules, and coagulating but feebly when drawn from its vessels. In the VERTEBRATA, there can be little doubt that the long course which the chyle traverses in the lymphatic system, contributes to prepare it for entering into the composition of the highly-elaborated fluid that supplies both the alimentary materials of their tissues and the necessary stimulus to their vital actions. The *Blood* of all the higher classes presents a decided red colour, when drawn from the arteries; and this is changed in the course of circulation into the dark purple tint which it exhibits in the veins. The colour exists only in the globules or corpuscles which are carried in its stream, the fluid portion being perfectly transparent and colourless; it appears due to the union of a minute quantity of iron with an animal compound, but not, as was formerly supposed, to oxide of iron alone. When the minute streams are examined in the living animal, flowing through the capillary vessels in which the globules usually arrange themselves in single file, they appear quite colourless; and it is only when these particles are collected into a mass that their tint becomes manifest. The composition of these two constituents of living blood,—the *globules*, and the fluid portion or *liquor sanguinis*,—will now be examined separately.

363. The form and size of the *coloured particles* vary considerably in different classes, but they are never so spherical as to deserve the appellation *globules* commonly given to them. In man and the other MAMMALIA they are round flat discs, resembling pieces of money in form; but their thickness is porportionably greater, being about $\frac{1}{4}$ or $\frac{1}{5}$ of their diameter. In BIRDS, REPTILES, and FISHES, they are almost always elliptical in form; the long diameter being usually about twice the short one. The average thickness bears about the same proportion to the short diameter; but a central prominence is observed on each side in many Reptiles and Fishes. This prominence is seen in the red particles of Frogs' blood (which are four times as long as those of the blood of man) to be occasioned by the presence of a central *nucleus*, which differs in chemical properties from the matter that surrounds it. Although the existence of a similar nucleus in the blood of Birds and Mammalia has been doubted, it seems now to be established; its presence in the red particle is not indicated, however, by a prominence, but by a dark spot which has been erroneously regarded as a depression.* Other globules are found in the blood,

* There can be no doubt that many errors as to the character of these bodies have arisen from the mode in which they have been studied. They can only be fairly examined in the serum of the blood itself (§ 365); since admixture of pure water changes their flattened form into a spherical one, and renders circular those which were elliptical. After a time, most of the coloured portion is dissolved, and the nuclei remain; but this effect is produced much more rapidly by acetic acid. Various circumstances lead to the belief that each particle is contained in a membranous envelope of great delicacy, which encloses, first the colouring matter in a semi-fluid state, and then the nucleus; and that the effects of water and other

however, which seem identical with those of chyle and lymph. They have been supposed to constitute the foundation, as it were, of the red-particles, being usually of about the same size with the nuclei; but they are not always of the same shape. These lymph globules may not only be found in blood drawn from the body, but they may be watched in the general current of the circulation,—especially in tadpoles, where they are sooner introduced into the veins than in higher animals. According to the observations of Ascherson* the velocity of the two sets of particles is different; the lymph globules moving slowly, especially in the neighbourhood of the sides of the vessel, where they are delayed by friction; whilst the red particles, being endowed with more perfect smoothness of surface, and a considerable degree of elasticity, are not so easily retarded by slight obstacles. There is some variation in the size of the red particles, even in the same individual; but none ever attain twice the average diameter. In the embryos of Mammalia, however, they are usually much larger than in the adult. In the INVERTEBRATA the globules seem to bear much resemblance to those of the lymph, in their want of a definite form, and in the roughness of their surface. In many species they occur very scantily, and their entire absence from some has been asserted. Their form often changes a good deal during circulation; but in some of the higher species, which border most upon Vertebrata, it seems more definite, and *nuclei* have been observed in them. The following are the average diameters of the blood-particles in different species, stated in parts of an inch.

Man	from $\frac{1}{4029}$ to $\frac{1}{2637}$	
Cat..................	$\frac{1}{7056}$	
Shark.........	from $\frac{1}{1107}$ to $\frac{1}{886}$	
Scorpion......	—— $\frac{1}{2215}$ – $\frac{1}{1938}$	
Asterias	—— $\frac{1}{5538}$ – $\frac{1}{1661}$	
Fowl	*long diam.* $\frac{1}{1681}$,	*short* $\frac{1}{2769}$
Tortoise......	—— $\frac{1}{1219}$,	— $\frac{1}{1955}$
Frog	—— $\frac{1}{997}$,	— $\frac{1}{1292}$
Cuttle-fish...	—— $\frac{1}{2769}$	
Snail	—— $\frac{1}{2769}$	

The nuclei of the red particles appear to consist of a substance resembling fibrin or coagulated albumen in most of its properties. The coloured envelope also has much affinity with fibrin in chemical composition; its characteristic property, however, is the change which its colour is capable of undergoing under the influence of various agents. Thus, when brought into relation with oxygen, whether pure or diluted, its florid tint is heightened, and carbonic acid is at the same time generated. Many saline solutions have a corresponding effect; and this is shown most evidently when the colouring particles are suspended in a saline mixture (such as their own serum), and exposed to oxygen at the same time. Most acids, on the contrary, render it dark; and carbonic acid seems to

reagents are due to an action of endosmose taking place through this membrane, by which its contents are increased, so far as even to rupture it,—or diminished, so as to cause a real depression on its surface.

* British and Foreign Medical Review, vol. vi. p. 219.

possess this power in a high degree. The application of these facts will be seen when the changes effected in the blood by Respiration are described (§ 418). This *cruorin*, as the colouring matter has been termed, is coagulated by heat and the mineral acids; and it then resembles fibrin in many of its chemical relations. When blood has been removed from the body, and diluted so as to prevent its coagulation, the particles are seen to be for some time in a state of constant movement. This is twofold,—the corpuscles moving towards each other, so as to arrange themselves in regular rows,—and each having a continual whirling motion of its own. The former may, perhaps, result from physical causes only; the latter, however, closely resembles that which has been already mentioned as occurring in the globules of the nutritive fluid of plants (§ 354), and which is witnessed in a still more remarkable form elsewhere (§ 519). It has been said that their movement cannot be the result of vitality, since it may continue, under favourable circumstances, for some time after the blood has been removed from the body. But it is to be remembered that the lower the degree of the vitality natural to each part, the longer is it usually retained; and that the ciliary movements (§ 110) might on the same ground be represented as purely physical, which no one has yet asserted.

364. The *liquor sanguinis*, or fluid portion of the circulating blood, is that in which the tendency to coagulate exists; and it is probably that which is chiefly concerned in supplying nutriment to the tissues,—the globules, so far as can be ascertained, being merely passive in the circulation. It consists of water, holding in solution fibrin and albumen with saline matter; and it also contains a small amount of fatty particles, though in less proportion than the chyle. Many other ingredients may be detected in it; but these seem to have the most important connection with the nutritive processes. The liquor sanguinis may be separated from the globules by a filter sufficiently fine to retain the latter; and it will then coagulate alone. This constituent of the blood is occasionally separated from it in the living system, under the form of *coagulable* or *plastic lymph*, which is sometimes effused as a product of inflammation, and sometimes for the simple purpose of reparation, and appears to consist of the liquor sanguinis in a concentrated form, the proportion of fibrin in it being especially large. When it is poured out on the surface of membranes, it has a tendency to become organised; new vessels, with lymphatics, and perhaps even nerves, are gradually formed in it; and these acquire connections with the neighbouring parts. Serous membranes are particularly liable to such effusions; and the *false membranes* thus formed very commonly produce adhesions between their adjacent surfaces. The newly-organised tissue at first presents the characters of simple cellular structure; but it gradually, in many instances at least, assimilates itself to the tissue with which it is connected. There seems no doubt

that the formation of vessels usually commences in the substance of the coagulated fluid thus effused, and that the canals gradually form connections with those of the neighbouring parts; but what is the precise manner in which this process is effected still remains a mystery. It is almost impossible to consider it without admitting that the liquor sanguinis is as completely possessed of vitality as any solid tissue in the body; since it exhibits properties which no merely chemical admixture can possess. Fibrin is sometimes effused in a similar manner into the substance of organs, and, by becoming organised, converts that into a solid mass which previously possessed a spongy texture;—as when the lungs are *hepatised* by inflammation, and their air-cells obliterated. It is by an analogous process of organisation in effused fibrin that the reparation of injuries takes place; and whatever may be the nature of the tissue to be subsequently regenerated, the effusion of coagulable lymph, followed by its conversion into cellular structure, is always the primary change.

365. The blood drawn from the living body does not long remain in the fluid form in which it exists in the vessels; but undergoes a process of spontaneous coagulation, separating into a solid *crassamentum* or clot, and a fluid *serum*. The former is composed of the red particles held together by the fibrin, through which they are usually diffused pretty equably; if, however, the coagulation be retarded, either by the condition of the system at the time the blood was drawn, or by artificial means, the red particles will sink, leaving the surface of the coagulum nearly free from colour, so as to form what is termed the *buffy coat*. The serum consists of the watery portion of the blood, which holds in solution the greater part of the albumen with the saline matter and most of the other elements; it is coagulable by heat like other albuminous fluids. This is not unfrequently separated from the blood in the living state; the natural secretions of serous membranes (§ 36) appearing to differ but little from it; and the collections which sometimes take place to a great amount in their cavities, presenting nearly all its characters. In inflammatory conditions of these membranes, more or less fibrin is generally contained in the serous effusion, the flakes which are suspended in it giving it a turbid appearance. The spontaneous coagulation of the fibrin can scarcely be regarded in any other light than as a result of the vital properties with which this principle is endowed. It has been shown to serve a most important purpose in the economy of the living system; the fluid form, which the fibrin retains as long as it exists within living vessels, enabling it to be conveyed wherever it may be needed for the purposes of nutrition or reparation,—whilst, as soon as it is deposited by them in connection with parts already organised, it manifests a tendency to partake of their structure.* The

* A curious instance of the tendency of fibrin to become organised came under the author's observation whilst Clinical Clerk to Dr. Watson at the Middlesex Hospital. A patient labouring under endocarditis (inflammation of the lining membrane of the heart) having been bled,

vitality of the tissues with which it is contact, however, seems to have an important influence on its condition. Blood will not remain fluid in a portion of a vessel isolated by ligatures (§ 359, *note)* longer than the healthy structure and properties of its coats are retained; and it is by its tendency to coagulate in any part where these are impaired that hemorrhages are often prevented or checked. Again, it has been found that violent injuries of the nervous centres (especially the breaking down of the brain and spinal cord) very rapidly produce coagulation of the blood whilst it is yet moving in the vessels, by destroying the vitality of their coats. On the other hand, coagulation does not take place after some kinds of sudden death, in which the vitality of the whole system appears to have been instantaneously destroyed (as when an animal is killed by lightning or by a violent electric discharge); and, in these cases, the usual stiffening of the muscles (a change that seems to result from a similar change in their constitution, which may be regarded as a last effort of vitality,) does not take place. Of the various conditions which hasten or retard the coagulation of the blood, more cannot here be said; but the subject is one of much interest and importance.

366. Of the means by which the nutritious materials of the blood are converted into organised tissues, and of the mode in which this takes place, little can be said in addition to what has been already stated. There can be no doubt that the constituents of all these tissues exist in the blood, in a form very nearly allied, except so far as their organisation is concerned, to that which they possess in the solid parts; since its elements may be obtained from them by chemical analysis. Thus, the fibrin is particularly found in muscles, albumen in cellular tissue and its modifications, the oily particles in the fat and in the nervous matter, phosphate of lime in the bones,—and so on. But another proximate principle is abundantly yielded by many tissues, which cannot be detected (except, perhaps, in very small quantity) in the blood. This is *gelatine*, familiarly known as glue. Its characteristic properties are its solubility in warm water, and its coagulation on cooling; and its precipitation by tannin as a new compound, on the perfect formation of which the conversion of skin into leather depends. By long-continued boiling, gelatine may be obtained, in greater or less proportion, from almost all the animal tissues; but it is doubted by many chemists whether some chemical change is not thus effected in their constitution, and whether gelatine, *as such*, exists in the living body. It may be regarded as composed of 7 eq. of carbon, 7 eq. of hydrogen, 3 eq. of oxygen, and 1 eq. of nitrogen; and it thus differs from albumen in the deficiency of one proportional of carbon. The conversion of the albumen

the coagulum exhibited at its edges a number of little wart-like processes, exactly resembling in character the softer granulations which are seen on the cardiac valves after death from this disease.

of the blood, therefore, into the gelatine of the tissues (or into whatever principle occupies the place of that which is known as gelatine in a separate form) may not improbably be the source of the carbon set free during the circulation of the blood through the system (§ 418).

367. It is in the capillary vessels only that the nutritive changes take place between the blood and the tissues which they permeate. It has been maintained by some that these vessels have no distinct coats, and that they are merely channels through which the fluid moves. The latest observations, however, permit little doubt that, in the perfect tissues of the higher animals, each ramification, however minute, is a regular tube possessing distinct walls of its own; but that in the lower tribes, as in the newly-forming tissues of the higher, the simpler condition is retained in which these exist in plants (§ 288). The movement of fluid through them appears in all instances to be much influenced by the activity of the nutrient processes, and in some cases to depend entirely upon them. Each tissue seems to derive from the blood the materials it requires, and to convert it into an organised structure like its own. More minute details on their respective modes of growth and increase cannot, however, be given, until the difficulties which impede the observation of them shall have been much diminished. The actual processes of organisation probably correspond, so far as they take place, pretty closely in all animals; the differences between the higher and lower tribes consisting more in the preparatory stages, and in the varieties which arise at a later period.

368. Although, as formerly stated (§ 226), the function of Nutrition does not seem to have any immediate dependence upon the nervous system in Animals, any more than the corresponding process in Plants, there can be no doubt that it is greatly influenced by changes in the condition of that system, whether these be the result of states of mind or those of other parts of the material organism. Thus, if a limb be paralysed by the division of its nerve, it loses after a time its healthy firmness, its muscles become pale and flabby (sometimes even showing little trace of true fibres, and losing their contractility), and it is peculiarly liable to be injuriously affected by changes of temperature or by external applications, which produce no perceptible change in sound parts. Again, if the nerves supplying mucous membranes be divided, these parts are very liable to become inflamed; for the secretion is no longer formed which protects them from the contact of irritating matter. That the general function is liable to be influenced by the state of the mind, every one must have observed; still this may be affected, not only *immediately* by the influence of the nerves, but by an imperfect preparation of the alimentary materials in the digestive cavities, which may result from deficiency or want of solvent power in their secretions,—the formation of these last being manifestly influenced, like nutrition, by the condition of the system at large. The doctrine of the dependence of animal nutrition

on the influence of the nervous centres is opposed to the fact that, in the early evolution of the organism, its processes go on most energetically, long before these nervous centres are formed, and even before the presence of nervous matter can be detected; and that the formative processes by which new structures are created in the adult appear equally removed from their direction. In the present state of our knowledge we can only refer these processes to the property which living structures appear to possess, of converting into textures, similar in character to their own, certain proximate principles endowed with a capacity of being thus organised.

CHAPTER IX.

RESPIRATION.

General Considerations.

369. Although this has usually been considered in the light of a distinct function, there is no longer reason for so regarding it; since the structure of glands being now more fully understood, that of the respiratory organs is perceived essentially to correspond with them, whether these are formed into external prolongations—such as the leaves of plants or the gills of aquatic animals—or into the internal cavities which constitute the lungs of the air-breathing Vertebrata. The modifications which exist have all reference to the peculiar conditions required for this function,—namely, the exposure of the nutritive fluid to atmospheric air (either in a pure state or as contained in water) through the medium of a thin membrane; and it is very obvious that provision must be made, not only for the continual transmission of this fluid through the respiratory apparatus, but for a continual renewal of the air in contact with the outer surface of the membrane. It appears that the interchange of ingredients between the circulating fluid and the atmosphere, which constitutes Respiration, has for its chief object the liberation of a portion of the superfluous carbon of the system, in the gaseous form which it assumes when united with oxygen. There is no doubt, however, that the quantity of oxygen and nitrogen in the structure, as well as of carbon, is partly maintained at its proper standard by the same means; and that, in plants, carbon is introduced into the system from the atmosphere, as well as excreted by it. All these changes may be comprehended under the general term of the *aeration* of the circulating fluid, and would seem to take place under the same general conditions; but the liberation of carbonic acid, by the union of the superfluous carbon of the system with the oxygen of the atmosphere,

is that which peculiarly constitutes *respiration;* and upon that, as will be hereafter seen, the maintenance of the temperature of the system is probably dependent.

370. The *aeration* of the nutritious fluid, would appear to be, like absorption, a change dependent on physical laws, and occurring in conformity with them, when the requisite conditions are supplied by the structures of an organised being, and by the functional alterations which the living state involves. The physical laws alluded to, and the phenomena which are exhibited in conformity with them, will be now briefly described.

371. All gases of different densities, which are not disposed to unite chemically with one another, have a strong tendency to mutual admixture. Thus, if a vessel be partly filled with hydrogen, and partly with carbonic acid, the latter, which is 22 times heavier than the former, will not remain at the bottom, but the two gases will be found in a short time to have uniformly and equably mixed; and it is on this principle that the constitution of the atmosphere is every where the same, although the gases which compose it are of very different specific gravities. The same tendency exists also with regard to two volumes of the same gas or mixture, possessing different degrees of heat, and therefore different densities, until by their mutual penetration the temperature becomes the same throughout. So strong is this tendency to admixture on the part of different gases, that it will take place when a membrane or other porous medium is interposed between them. When, for instance, a bladder of hydrogen is placed in an atmosphere of carbonic acid, a certain quantity of hydrogen will pass out; but a much larger proportion of carbonic acid will enter, so as to distend the bladder even to bursting. This interchange, therefore, evidently resembles the endosmose and exosmose of fluids; and although the tendency to admixture of the two gases is the fundamental cause of their movement, the nature of the septum has so much influence over the phenomenon as sometimes to reverse the results. When plaster-of-paris is employed as the medium of diffusion, the exchange will take with simple relation to the relative densities of the gases; and a general law has been ascertained by Professor Graham, which applies to all instances,—that the replacing or mutual-diffusion volumes of different gases vary inversely as the square-roots of their densities. Thus, if a tube, closed at one end with a plug of plaster-of-paris, be filled with hydrogen, the gas will soon be entirely removed, and will be replaced by something more than one fourth of its bulk of atmospheric air; the density of hydrogen being about $\frac{1}{14}$ that of the atmosphere. But when organic membranes are employed, the result is much influenced by the relative facility with which each gas permeates the septum. Thus, carbonic acid passes through moist bladder much more readily than hydrogen; and, in consequence, the result occurs which has been mentioned above, and which seems contrary to the law

just stated. It would not seem improbable that the phenomenon of endosmose is dependent upon laws precisely similar, and that its anomalies are of a kind which experiments on the gases would much elucidate.

372. Further, it is found that if a fluid be charged with any gas which it will absorb (as, for example, water with carbonic acid), it will speedily part with it when exposed to the attracting influence of another gas, such as atmospheric air; and the more different the densities of the two gases, the more rapidly, and with more force, will this take place. As in the former instance, this attraction will go on with little interruption, through a porous membrane; and part of the exterior gas will be absorbed by the fluid (if of a nature to be so imbibed) in place of that which has been removed. These simple phenomena will be found a key to the explanation of the changes which take place in the aeration of the circulating fluid by exposure to air; for it seems a universal fact that *carbonic acid* existing in that fluid is exhaled and replaced by absorbed *oxygen;* and that an exhalation and absorption of *nitrogen* take place in animals, and perhaps also in plants.

Respiration in Plants.

373. As already stated (§ 235), two distinct changes, both nearly constant throughout the Vegetable kingdom, have been associated under this function. The air being the chief source whence carbon is supplied to the living plant, the introduction of that element has been confounded with the contrary change, which is also necessary for the continued health of the structure, and which corresponds exactly with the respiration of Animals. The introduction of carbon is effected by the power which the surfaces of plants possess (especially those which are green) of decomposing, under the stimulus of light, the carbonic acid contained in the atmosphere. This process is one which our knowledge of the application of physical laws can but little elucidate, and we must be content to regard it as a phenomenon of an essentially vital character. Its conditions may, however, be advantageously enquired into. If we place some fresh leaves in an inverted jar containing an atmosphere charged with 7 or 8 per cent. of carbonic acid, and expose them to strong sun-light for a few hours, it will be found that a large proportion of the carbonic acid will have disappeared, and will be replaced by pure oxygen. If, on the contrary, we cause a plant to grow in a dark situation, with even a less proportion of carbonic acid in the atmosphere around it, it will soon become sickly and die; and if in common air, under similar circumstances, it will lose its colour, and thus be *etiolated* or blanched, from the want of the supply of carbon which it can only obtain under the influence of light. It is found that no degree of artificial light will produce this change; and that the proportion of carbonic acid in the atmosphere is that which is most

favourable to growth under the average amount of the stimulus which this climate affords.

374. As to the organs by which this process of *digestion*, as it may reasonably be called, is performed by the different classes of plants, it is difficult to speak with certainty. In the PHANEROGAMIA, the green surfaces of the leaves, stems, &c., are those by which the fixation of carbon is chiefly, if not entirely effected. In general, it is by the upper side of the leaf that the greatest amount of this function is performed; as would be supposed from its greater exposure to the light, and as is evinced by its brighter colour. But in other cases, the two sides are equally exposed to light, and then their colour is the same. In the FERNS, MOSSES, &c. there is the same separation of parts as in the flowering plants; and the process is here also, without doubt, performed by the green parts of the surface. Of the inferior CRYPTOGAMIA, however, we know very little. The FUNGI would not seem to depend upon the atmosphere for any part of their supply of carbon, which is altogether furnished by their peculiar aliment (§ 235); and these plants scarcely ever present any green surface, and flourish most in situations to which light has but little access. The same may be said of the *Cuscuta* (broom-rape) and other parasitic plants of more complex structure, that live upon the prepared juices they derive from the plant to which they attach themselves. There can be no doubt that LICHENS derive the carbon which enters into their structure almost entirely from the atmosphere, and, that the ALGÆ are supported, in like manner, by the carbonic acid contained in the circumambient water; but experiments are yet wanting to ascertain the precise conditions under which its assimilation is effected. Few Lichens have any green surfaces; and although many of the Algæ are very brilliantly coloured, yet we find them occasionally existing at such depths as forbid us to believe that light is the only stimulus under which they can attain this appearance. Thus, Humboldt found near the Canaries a species of Fucus which was bright grass-green, although it had grown at a depth of 190 feet, where the light could only have been $\frac{1}{1500}$th part as intense as at the surface. The simpler forms of Algæ, especially the *Confervæ*, which inhabit fresh water,

* A very ingenious theory has been raised by M. Brongniart upon the fact that an increased quantity of carbon may, under particular circumstances, be assimilated by Vegetables. He supposes that, at the epoch of the growth of those enormous primeval forests which supplied the materials of the coal formation, the atmosphere was highly charged with carbonic acid, as well as with humidity; and that from this source the Ferns, Lycopodiaceæ, and Coniferæ of that era were enabled to attain their gigantic development. He imagines that they not only thus converted into organised products an immense amount of carbonic acid, which had been previously liberated by some changes in the mineral world, but that, by removing it from the atmosphere, they prepared the earth for the residence of the higher classes of animals. The hypothesis is a very interesting one, and well deserves consideration; but it may reasonably be enquired whence the increased light was derived which would be necessary (unless the laws of the vegetable economy at that period were different from those now in operation) for the increased assimilation of carbon to any such extent.

appear to exercise an important influence in maintaining it in a state fit for the support of animal life; since it seems probable that they absorb the products of the decomposition of that foul matter by which all ponds and streams are constantly being polluted, and at the same time yield a supply of oxygen to the water.*

375. The change which, strictly speaking, constitutes the *respiration* of vegetables is not, like that we have been describing, an occasional one; but is constantly taking place during the whole life of the plant, and appears to be more immediately necessary to its healthy existence. This consists in the disengagement of the superfluous carbon of the system, either by combination with the oxygen of the air, or (which is most likely) by replacing with carbonic acid the oxygen that has been absorbed from it. The respiration of vegetables is performed in part by their *dark* surfaces, and partly also by the covering of the leaves. It does not cease by day, by night, in sunshine, or in shade; and it has been shown that the leaves continue to disengage carbonic acid, even under the circumstances when the *fixation* of carbon is most actively performed.† If the function be checked, the plant soon dies,—as when placed in an atmosphere with a large proportion of carbonic acid, and without the stimulus of light which enables it to decompose the deleterious gas. Plants which are being etiolated by the want of light, absolutely diminish in the *weight* of their solid contents, owing to the continued excretion of carbon by the respiratory process, although their *bulk* may be much increased by the absorption of water; and if the proportion of carbonic acid in the surrounding air be increased by its want of renewal, they become sickly and die, from the impediment to their respiration. The parallel, therefore, between plants and animals appears to be complete as regards the influence of carbon upon their growth; for to both it is deleterious when breathed, and to both it is invigorating to the digestive system when absorbed as food.

376. It becomes a question of much interest to ascertain the relative amount of carbon thus absorbed and excreted by Vegetables. If it be true, as was stated (§ 234), that a large part of the solid materials of

* It is a notorious fact that fishes are never so healthy in reservoirs destitute of aquatic plants, as in ponds and streams in which they abound. Besides the use of these plants in setting free oxygen in the water, it is not impossible that the jelly-worts (as some of them are occasionally called) enable the fluid to retain a larger quantity of gas in mixture with it, than pure water would do; for it appears that, like some mucilaginous beverages (beer or ale, for example), such water gives out by heat or in a vacuum a larger proportion of air than it naturally contains. Burnett's Botany, p. 77. The floating islands which are constantly being formed in the lake Solfatara in Italy, exhibit a striking example of the luxuriance of cryptogamic vegetation in an atmosphere impregnated with carbonic acid. These islands consist chiefly of Confervæ and other simple cellular plants, which are copiously supplied with nutriment by the carbonic acid that is constantly escaping from the bottom of the lake with a violence which gives to the water an appearance of ebullition. See Sir H. Davy's "Consolations in Travel," 3d ed., p. 116.

† Journal of the Royal Institution, N.S., vol. i.

their tissues is derived from the atmosphere, it would be evident that the quantity of carbonic acid in the air must be diminished by their growth. This, from the best-conducted experiments, appears to be the case; for the amount of carbon assimilated by a healthy plant during a period of ordinarily clear weather is found to exceed that exhaled by respiration, although the former is an occasional change, and the latter a constant one. From the data presented to us by Dr. Daubeny it is shown that a plant consisting of leaves and stems, if confined in the same portion of air, day and night, and duly supplied with carbonic acid gas during sunshine, will go on adding to the proportion of oxygen present, as long as it continues healthy; the slight diminution of oxygen and increase of carbonic acid which take place during the night, bearing no considerable ratio to the degree in which the opposite effect occurs by day.

377. There is one tribe of plants, the FUNGI, in which we see the effects of a Respiration performed almost as actively as that of animals, and unobscured by any opposing changes. From the late experiments of Marcet, it appears that growing mushrooms absorb from the air a large quantity of oxygen; a portion of which appears to combine with the carbon of the plant, and thus to form the carbonic acid which replaces it; whilst the rest seems to be retained in its structure. The large quantity of carbonic acid disengaged from the soil in which alone the Fungi thrive, renders it necessary that the superabundant carbon of the plant should be constantly removed by the atmosphere, instead of any addition being received through that medium (§ 235).

378. The balance of nutrition, therefore, between the Animal and Vegetable kingdoms is thus maintained in a very perfect and interesting manner. Plants convert the carbonic acid of the atmosphere into organised tissues, although the conditions of their growth require that part of the materials so introduced should be restored to the surrounding medium; these tissues serve for the nutrition of the whole animal kingdom, which is immediately or remotely dependent upon them; and the large amount of carbonic acid which is constantly being excreted from *their* bodies in the living state, (perhaps owing to a slow decomposition of their structures, § 18), with that disengaged during their final decay, restore to the atmosphere the ingredients which are required for the maintenance of fresh generations of organised beings.

379. With regard to the changes effected by vegetation upon the principal constituent of the air—nitrogen—no very certain or definite statement can be made. It has long been known that this element enters largely into some of the products of secretion; but it has been usually supposed not to constitute a part of the organised structures themselves. The experiments of M. Payen already alluded to (§ 250), however, showed that the tissue of the absorbent vessels, especially near the extremities of the roots, is acted on by tannin in the same manner as animal

membrane, and therefore probably contains an azotised principle. And the recent analyses of Mr. Rigg,* seem to have proved the existence of this element as an essential constituent of all those parts of the vegetable structure, which perform the most important offices in the economy. When the required amount of this gas is not taken up by the roots in a state of solution, it must be absorbed from the atmosphere; but as all the water which is imbibed contains more or less of common air, it is probable that a sufficient supply is generally thus obtained. Indeed, the few experiments which have been performed with express view to this subject lead to the belief that azote is more frequently exhaled than absorbed. Wherever the plant is supplied with rich animal manures, the fluids absorbed from which contain more azote than it can assimilate, we should expect to find it disengaged in some quantity; this is the case in the Fungi, although their tissue contains more nitrogen than that of any other tribe of plants.

380. There are two periods during the life of plants in which the function of Respiration appears to go on with remarkable activity. The first of these is *germination*, or the development of the young plant from seed (§ 50), which requires that the starch laid up by the parent for the support of the embryo should be converted into sugar, the latter being the form in which it is applied to the purposes of nutrition. This conversion (§ 350) involves the liberation of a quantity of carbon, which is disengaged precisely in the manner in which it is set free at a later period of vegetable life,—namely, by its combination with the oxygen of the surrounding atmosphere. Germination takes place most readily in the dark, since this most essential part of the change would be antagonised by the influence of light. The young plant is, therefore, much in the condition of one which is being etiolated; and it is accordingly found that, during the early period of germination, the weight of the solid contents of the seed diminishes considerably, though its bulk increases by the absorption of moisture. This is its state until the *cotyledons* or seed-leaves have arrived at the surface, and temporarily perform the functions of leaves. It is an interesting fact that, after many trials, germination has been found to take place most readily in an atmosphere consisting of 1 part oxygen and 3 parts nitrogen, which is nearly the proportion of the air we breathe. If the quantity of oxygen is much increased, the carbon of the ovule is abstracted too rapidly, and the young plant is feeble; if the proportion is too small, carbon is not lost in sufficient quantity, and the young plant is scarcely capable of being roused into life.

381. The changes which place during *flowering* are very similar to those occurring in germination. A large quantity of oxygen is converted into carbonic acid by the action of the flower; and it is believed that the fecula or starch, previously contained in the *disk* or receptacle (§ 349), is

* Proceedings of the Royal Society, May, 1838.

changed by this process into saccharine matter adapted for the nutrition of the pollen and young ovules, the superfluous portion flowing off in the form of honey. It is remarkable that this analogy between germination and flowering holds good, not only in their products, but in the conditions essential to their development. Neither will commence except in a moderately warm temperature; both require moisture, for flowers will not open unless well supplied with ascending sap; and the presence of oxygen is in each case necessary. It has been well ascertained that the carbonisation of the air bears a direct relation to the development of the glandular disk, and that it is principally effected by the essential parts of the flower, or organs of fructification. Thus, Saussure found that the *Arum Italicum*, whilst in bud, consumed in twenty-four hours, 5 or 6 times its own volume of oxygen; during the expansion of the flower, 30 times; and during its withering, 5 times. When the floral envelopes were removed, the quantity of oxygen consumed by the remaining parts in proportion to their volume was much greater. In one instance the sexual apparatus of the Arum Italicum consumed in twenty-four hours 132 times its bulk of oxygen. Saussure also observed that double flowers, in which petals replace sexual organs, vitiate the air much less than single flowers in which the sexual organs are perfect. (See also § 480).

382. Besides the means of aeration which the transmission of the nutritive fluid to the external surface affords, the more highly organised plants seem to have the power of admitting air into cavities existing in the leaves, (especially beneath their inferior cuticle Fig. 69) through their *stomata;* and in this manner a much larger extent of membrane is exposed to its influence. The peculiar organisation which is probably subservient to this purpose will be hereafter described (§ 429) under the head of *exhalation*, for which function it appears more particularly designed. But, superadded to this, we find in the Phanerogamia a system of tubes apparently designed to connect the interior of the structure with the external air. These are the *spiral vessels* (§ 26), which, in their perfect form, are never found to contain any but gaseous fluids. In EXOGENS they usually exist in only one part of the stem, being confined to the *medullary sheath*, a delicate membrane, principally formed by them, which immediately surrounds the pith. In ENDOGENS they are more universally distributed through the stem, forming part of every bundle of fibro-vascular tissue. In each case, however, they traverse the stem for the purpose of entering the leaves; and they seem to communicate with the intercellular passages, and, through their medium, if not more directly (as some have supposed), with the external air. We have already noticed the curious analogy between these respiratory tubes and the *tracheæ* of insects; and although their exact office is not fully ascertained, there can be little doubt that they contribute in some way to the aeration of the

internal fluids. It has been found that they contain a larger quantity of oxygen by 7 or 8 per cent. than that which exists in the atmosphere.

383. In a great number of the aquatic tribes, both among the simpler and the more highly organised plants, we find cavities expressly adapted for the inclusion of air, which would seem designed to give buoyancy to the structure. Thus, the roots of the *Utricularia* are furnished with a number of bladder-like vesicles; the whole surface of the *Fucus vesiculosus* (bladder-wrack) is studded with similar ones; whilst in the leaves of the Duck-weed or Water-lily, or the stem of the *Lymnocharis* we find hollows surrounded with regularly-built-up tissue, evidently answering the same purpose. These present an obvious analogy to the air-bags with which various aquatic animals are furnished, from the vesicles of the Physalia (Portuguese man-of-war, Fig. 140) to the swimming bladder of fishes. As the air which they contain is seldom identical in composition with that of the atmosphere, it has been conjectured that they have some connection with the function of Respiration; but on this point no certain conclusions have been obtained. It is desirable, however, that these regular air-passages should be distinguished from the irregular hollows which are occasionally found—as in the stems of grasses, umbelliferous plants, &c.—and which simply result from the expansion of the external tissues faster than the interior can be filled up by the materials ready.

384. Although the leaves are to be regarded as the special organs of aeration in the plants furnished with them, yet there is no doubt that the remainder of the surface is more or less concerned in this function; the green parts probably assimilating carbon wherever they exist, and the dark portions, especially the roots, disengaging carbonic acid. That the access of oxygen to the roots is necessary for the health of the plant is well known; but this may be required for the decomposition of the organic matter which surrounds them. It has often been found that, if an additional stratum of soil be laid over the roots of a large tree, either they will send up fibres nearly to the surface; or, if they be not strong enough to do this, the tree will perish.

385. Regarding the progressive evolution of the respiratory system in plants, much might here be said which will perhaps be more advantageously deferred to the account of their development in general (CHAP. XIII.). It may be remarked, however, that the early condition of the embryo of the flowering plants resembles, in its want of special organs, the simple vegetation of the cellular Cryptogamia, although it differs in the mode in which nutriment is supplied; the latter deriving it by their unassisted powers from the surrounding elements, whilst the former is provided with it by the parent. At the first period of the germination of the seed, a curious analogy may be traced between the growing embryo and the tribe of Fungi. Both are supplied with nutriment previously

organised, the one from its parent and the other by the decay of animal or vegetable matter; both are developed most rapidly when supplied with warmth and moisture, and in the absence of light; and both liberate carbon to a large amount without assimilating any from the atmosphere. By the time, however, that the cotyledons have risen to the surface and acquired a green colour, the plant has advanced a stage in its growth, and the respiratory system has now arrived on the level of the Marchantia (§ 61), possessing, like it, stomata and intercellular spaces, but being destitute of spiral vessels. These do not appear until true leaves are evolved; and as soon as this last stage in the development has taken place, the cotyledons, which may be regarded as temporary respiratory organs, decay away. When we have traced the evolution of the respiratory system of animals in a similar manner, we shall observe a most interesting correspondence between the consecutive phenomena, as they occur in the two kingdoms.

Respiration in Animals.

386. In the Animal Kingdom, we find Respiration exerting a more immediate, though perhaps not in reality a more powerful influence over the system, than in Vegetables. The dependence of the organism on the constant stimulus of the circulating fluid is more evident in proportion as, in ascending the scale, we meet with greater variety and activity in the vital operations. The maintenance of the vivifying powers of this fluid by its exposure to the atmosphere is, therefore, demanded more urgently than the mere supply of its deficiency by the ingestion of fresh aliment; and it is accordingly found that many animals are capable of subsisting a considerable time without nourishment, whilst there are few which do not speedily perish, or whose vital *actions* at least are not checked, when deprived of air. The correspondence between the activity of this function in any individual system, and its general vital energy, must be evident to the discriminating observer; the comparative energy of the respiration in the active and rapacious eagle, and in the timid and indolent tortoise, afford a ready illustration of the connection. The development of the locomotive powers, and the degree of heat maintained in the system, which may be regarded as pretty constant indications of the general activity of its organic functions, will be found peculiarly connected with that of respiration. In making comparisons of this kind, however, we must bear in mind that the absolute amount of respiration does not depend upon the comparative bulk of the organs, but on the extent of surface by which the blood is exposed to the action of the air; so that the minutely-partitioned cellular lungs of a rabbit present greater opportunity for the aeration of the blood than the capacious undivided sacs of a turtle ten times its size.

387. The organs appropriated to the performance of the function of

respiration in the various classes of the Animal Kingdom, appear at first sight so very different, that a superficial observer would hardly trace any analogy between them (§ 195). A little reflection, however, will show, that all their forms are reducible to the simple element of which the respiratory organs are constructed in the Vegetable kingdom;—an extension of the external surface, peculiarly adapted, by its permeability to gases, for the interchange of ingredients, between the circulating fluid brought in contact with one side of it, and the atmosphere which it touches on the other. This extension usually takes place internally or externally according as the animal is to be an inhabitant of the air or the waters. In animals modified for atmospheric respiration, the air enters the system to meet the blood; a peculiar set of movements, more or less complicated, being appointed for its constant renewal by successive inhalation and expulsion. In those adapted to an aquatic residence, a different plan is required. The small quantity of air contained in the water is all that the respiratory system employs; and it would have been a useless expenditure of muscular exertion to have provided means for the constant inspiration and expiration of a large amount of so dense a fluid. In most aquatic animals, therefore, the aerating surface is extended outwardly, instead of being prolonged inwards; and the blood is propelled through it so as to come in relation with the surrounding medium, the portion of which in contact with it is constantly being renewed, either by the natural movements of the animal, or by others more expressly contrived for the purpose. In tracing upwards the different forms of the respiratory apparatus through the principal classes of animals, we shall observe the same gradual specialisation which has been noticed in the other systems; for, beginning with the lowest, it will be seen that the general surface is the organ of respiration as well as of other functions; whilst, in the highest, the aeration of the blood is almost entirely effected in one central apparatus adapted to it alone, although the general surface is not altogether destitute of participation in it.

388. In the simplest forms of animal life, which are all aquatic, the almost homogeneous tissues are immediately nourished by absorption from without, as in the PORIFERA; and the constant movement of fluid through their ramifying canals answers the purpose of aerating their tissues, as well as of supplying them with nutriment. In the INFUSORIA, which also seem unprovided with special respiratory organs, we detect an apparatus which ministers not only to locomotion and the ingestion of food, but to the aeration of the fluid constituents of the organism, by perpetually renewing the surrounding water. The rows or tufts of the vibratile cilia (§ 110) by which these objects are fulfilled, are variously distributed in different species; in the gemmules of the Sponges and Polypes, which are destitute of internal canals of any kind, the surface of the body is covered with them; but in the Infusoria they are usually

disposed around the mouth; and they are arranged as a fringe on the tentacula which border this orifice in the POLYPIFERA. We have no reason to believe that any minute distribution of capillary vessels exists in species so simply organised; and the supposition that each of these cilia, like the filament of a fish's gill, is composed of bloodvessels prolonged into the water for the purpose of aerating their contents, is scarcely tenable. It is, however, by no means improbable that the internal prolongation of the surface which lines the digestive cavity, may be connected with the respiratory function as well as with that of absorption (a combination which we find in the foliaceous expansions of plants), in the cases where no more special structure is evolved. "The bodies of these animals," as Dr. Grant has remarked, "are not yet covered with solid shells, or with dense impervious scales, or with other hard materials which would exclude the general respiratory influence of water, and necessitate the formation of gills and lungs; but consist of the soft cellular tissue in which all higher organisations are at first developed. The few kinds which are furnished with a thin transparent or siliceous pellicle, have the power of extending the ciliated part of their body from beneath it: and thus of effecting all the required respiration."

389. The same observation will probably apply to the ACALEPHÆ, the soft external tegument of whose bodies would seem to afford sufficient means for the aeration of the nutritious fluid, where the constant change of the medium to which it is exposed is provided for by the organs of motion. It has been mentioned that, in the *Medusa* and other similar animals, prolongations of the digestive canals ramify on the margin of the mantle, which, being the most moveable part of the body, exposes them to a constant interchange of the external element with which they are in relation (§ 269); and the special vascular system developed in the *Cestum Veneris*, *Beroe*, &c. sends similar prolongations along the ciliated margins, which appear destined rather for the aeration of their fluid than for the purposes of nutrition (§ 294). In this beautiful and interesting class, we not unfrequently meet with large sacs containing air, which often, in fact, constitute the bulk of the animal, and most attract the attention of observers (Fig. 140). Whether or not these serve any other purpose than that of giving buoyancy to the structure, and of occasionally receiving the impulsion of the wind, is still uncertain; nor has the gas contained in them been analysed. The animals appear to have considerable power over their degree of distension; for whole fleets of the elegant "Portuguese men-of-war," which variegate with their brilliant colours the surface of the ocean on a calm day, will suddenly sink into the water and disappear when a storm is threatened.

390. In the class ECHINODERMATA a distinct respiratory apparatus is evolved, which is required, not only by the increased energy of the animals, manifested in their powerful muscular contractions, and by the

development of a special circulating system, but by the condensation of the external tegument, which is no longer capable of serving, as in the classes we have been considering, for the aeration of the fluid portion of the tissues it encloses. Contrary to the general principle which has been stated, that in aquatic animals the circulating system is prolonged outwardly, bringing the blood to meet the air contained in the dense element, we find that the respiratory apparatus of this class consists of a large cavity, from which a series of tubes ramifies minutely (in the higher species at least) through the body, and conveys the aerating fluid into every part of the structure. This cavity embraces the intestinal canal and other viscera, the exterior walls of which are therefore in contact with the fluid it contains; it is obviously analogous to the peritoneal cavity of higher animals; and though this is generally a closed sac, yet some traces of a similar conformation may be discovered in the Crocodile. The membrane which lines it in the Echinodermata is sufficiently muscular to execute the movement necessary for the transmission through its ramifying prolongations of the water which it inspires; and in the *Holothuria*, the leathery covering of which admits of more distension than the hard envelope of the Star-fish or the unyielding shell of the Echinus, so much water is sometimes taken in that the bulk of the animal is several times increased, and, by contraction of the cavity, the fluid may be expelled with considerable force.

391. The Molluscous classes presents great variety in the form and situation of their organs of respiration, although they are, with but few exceptions, inhabitants of the water. Most of these tribes are remarkable for the slowness of their movements, and many of them are entirely fixed; and it is beautiful to observe how all of them, even the most inert, are provided with means of renewing the fluid in immediate contact with their bodies, so as to aerate and renovate the blood. Although the form and position of the gills varies much in the different classes, their general structure is the same in all;—they consist of delicate membranous folds or tufts (prolongations of the external surface) minutely reticulated with blood-vessels, and covered with vibratile cilia, by whose action constant and regular currents are produced. These gills are usually situated within the cavity of the mantle, and are in fact expansions of the delicate membrane which lines it (like the *valvulæ conniventes* formed by the reduplication of the mucous membrane of the intestinal tube); and the entrance and exit of the water they require, are provided for by appropriate orifices, which are themselves fringed with cilia (§ 95). Sometimes the propulsion of the fluid is assisted by the general movements of the body; but not unfrequently the ejection of the expired water in a regular current is the principal means of locomotion with which the animal is endowed. In other instances, the gills are situated on the exterior of the mantle, and are formed in a corresponding manner by an extension of its membrane

into folds or tufts copiously supplied with blood-vessels. This is the case in many GASTEROPODA and PTEROPODA; and whilst, in the least perfect species, it is found that the general surface of the mantle, whether internal or external, seems adapted by its softness and vascularity for sharing in the aeration of the blood,—in those of higher organisation, in which a more powerful heart is developed, the branchial tufts or laminæ are restricted to particular parts, and the function appears confined to them alone. The branchiæ, when external, are generally disposed in such a manner as to be most influenced by the motions of the animal; thus, in the PTEROPODA they are situated on the fin-like processes by which these beautiful little Molluscs propel themselves through the ocean. Many of the GASTEROPODA are terrestrial, and are consequently modified for aeriform respiration. In the *Snail*, for instance, we find an opening on the right side of the body, which leads to a highly vascular sac destined to receive atmospheric air; this sac is placed nearly in the middle of the back, the position in which we find the air-bag in fishes; and though the surface it exposes is much smaller than that presented by tufted gills, it does not conduce less to the aeration of the blood, since the air is brought to it in a pure state, and not diluted by diffusion in water.

392. In ascending through the series of ARTICULATED animals, from the simple parasitic worms, to the highly-organised Insects or Crustacea, we find the respiratory apparatus assuming a more complicated form; and it is in this series that we first meet with beings capable of maintaining an active existence in the air. In the simple ENTOZOA, no special respiratory apparatus is evolved; and it is obvious that whatever aeration their fluids require must be performed by the external envelope, or by the reflexion of it that lines the digestive cavity. In the aquatic orders of the extensive class ANNELIDA, however, we find a special prolongation of the surface, adapted to that purpose. This sometimes assumes the form of delicate feathery tufts, disposed in a radiated manner round the head, and often displaying the most splendid variety of colours,—as in the *Serpula** (Fig. 144). In another portion of the class Annelida, the ramified tufts are disposed at intervals along the body of the animal, as in the common *Sandworm* (Fig. 145) or in the *Nereis* (Fig. 141). A third form of the respiratory apparatus exists in those species of the Annelida which are adapted to live in air as well as water, such as the *Leech* or the *Earthworm*. Here we lose the external gills or branchial tufts of the purely aquatic tribes, and find in their place a series of small bags, opening from their sides by minute orifices termed *stigmata*, and extending into the

* There are few sights more striking to the observer of nature in tropical regions, than the unexpected view of a bed of coral in shallow water, having its surface scattered with the brilliant tufts of the Serpulæ which have formed their habitations in it; the glowing and variegated tints of which, when lighted up by the mid-day sun, and contrasted with the sombre hues of the surrounding rocks, present an appearance compared to which the most beautiful garden of carnations (which flower the animals much resemble in form) sinks into insignificance.

interior of the body. No communicating tubes exist, however, between the sacs; nor do they send ramifying prolongations to distant organs; but this simple *inflexion* of the external surface cannot but be regarded as the rudimentary form of the complex respiratory apparatus of Insects. It is desirable to remark the connexion between the functions of respiration and locomotion in this class; the first indications of the evolution of special appendages for the latter purpose being discernible in those particularly adapted for the former. The motion of the branchial tufts of the Nereis is obviously one means of its propulsion through the water; although its progression is, no doubt, effected principally by the serpentine movements allowed by the general flexibility of the body. In some species, one of the filaments is prolonged and straightened into what is called a *cirrhus* (Fig. 142, 3, *a*), which possesses an obvious tubular structure, and is evidently the rudiment of the regularly-articulated members possessed by the succeeding classes. In the tribes modified for aerial respiration, the traces of the external organs are sometimes found in the *setæ* or bristles, of which a certain definite number are attached to every segment, (the earthworm possessing two pairs on each side), and which obviously serve as organs of locomotion; the species which are deficient in them, such as the leech, have the segments of the body very short and numerous, and thus possess greater flexibility of the trunk.

393. In the MYRIAPODA, the respiratory and locomotive systems are more definitely separated from each other. The increased hardness and want of flexibility of the tegumentary covering, requires both a more special apparatus for the aeration of the blood, and a more decided development of organs of propulsion. The prolonged *setæ*, therefore, of the higher Annelida here become regular jointed legs, endowed with considerable muscular powers; and as all of this class are inhabitants of the air, the respiratory surface is prolonged inwards in the form of canals ramifying through the body; but these *tracheæ* or air-tubes (§ 26), which arise from distinct stigmata, seldom have much communication with each other. In this form we may observe an intermediate condition between the insulated sacs of the air-breathing Annelida, and the complex distribution and frequent anastomosis of the tracheal system of Insects. In some of the higher species, however, two longitudinal canals have been observed, connecting together all the separate systems of tracheæ, such as will be presently shown in the larva of Insects.

394. In studying the respiratory system of INSECTS, we shall have occasion to observe several peculiar modifications which it undergoes for particular purposes, whilst its essential character remains unaltered; and we shall have also an opportunity of noticing the varieties of form and function which the same apparatus may present at different periods of life, and under changes in external conditions. The muscular energy required for the locomotive powers of the perfect Insect, and the general

activity of the organic processes, necessarily involve a large amount of communication between the nutritious fluid and the atmosphere; but, on the other hand, the low development of the circulating system would prevent the aeration from being accomplished with sufficient rapidity by the transmission of the blood through one particular organ. The difficulty is obviated by the introduction of the vivifying agent into every part of the body, by means of a complex and minutely-distributed system of tubes, which appear to ramify through even the smallest and most delicate organs, and which bring the air into immediate relation with all their tissues. This structure answers another purpose; for, by means of the distention of the body by gaseous fluid, its specific gravity is reduced, and it is maintained in the atmosphere with less exertion. We shall find indications of a similar adaptation in Birds, the insects of the Vertebrated classes, as they have been justly denominated. The extent of respiratory surface thus created is such, that the amount of the aerating changes performed by an insect in a state of activity, is not less in proportion to its bulk than that effected by the most energetic of the Vertebrata. It is impossible to view this subject philosophically without being struck by the fact, that this very high degree of respiratory power is given, not by a sudden advance to a more complicated and perfect system of organs, such as exist in the Vertebrated classes of animals, but by a extension of the comparatively simple plan of which we observed the first traces in the Annelida; thus affording a beautiful example of the great law of regular progression in the development of organs, which has few apparent and perhaps no real exceptions. Nor would it be easy for any reflecting mind to contemplate the manner in which the air is thus brought into contact with the blood in the minutest textures of the body,* without a feeling of admiration at the contrivance shown in the compensation of the limited circulation of the fluids by the extensive distribution of the respiratory apparatus; and at the means by which the necessary lightness, elasticity, buoyancy, and muscular energy are imparted to the bodies of these beautiful and interesting inhabitants of the air.

395. In the Larva condition of such aerial insects as undergo a complete metamorphosis, and are therefore most different in their early state from their ultimate character, the respiratory system much corresponds with the type it had attained in the higher Myriapoda. We find it entirely consisting of ramifying *tracheæ*, connected with the external air by the *stigmata* that open on the sides of the body; and freely communicating with each other, especially by the two longitudinal tubes

* A French Microscopist, M. Bernard-Deschamps, imagines, not without show of probability, that the tracheæ are even continued into the scales which clothe the membrane of the wings. Many of these, after their coloured lamina has been removed, exhibit a series of lines directed towards the point by which the scale is attached to the wing. (Ann. des Sci. Nat. N. S. Zool. iii).

which traverse its length, and into which the stigmata open by short straight passages (Fig. 147). Of the peculiar structure of these tubes a description has already been given (§ 26); and the change which they undergo in the metamorphosis of the insect will therefore be now briefly stated. Just as the Larva is passing into the Pupa state, the larger tracheæ exhibit dilatations at intervals, which are subsequently developed into expanded sacs that sometimes attain considerable size. The efforts which the animal makes at the moment of transformation to rupture its skin by the distention of its body, appear to contribute towards the expansion of these sacs, the formation of which had previously commenced.* One remarkable portion of the tracheal system, also, the incipient evolution of which may be detected in the Larva state, now shows an increased tendency to prolongation;—that namely which forms the wings. It may be regarded as absurd to maintain that the wings of insects are a part of the respiratory apparatus; but that such is really the case, is shown by the consideration of their perfect structure, and of the history of their development (§ 194 *note*). During the first metamorphosis of the *Sphinx ligustri*, as observed by Mr. Newport, the wings, which at the moment of slipping off the larva skin were scarcely as large as hemp-seeds, have their tracheæ distended with air; and, at each inspiration of the insect, are gradually prolonged over the trunk by the propulsion of the circulating fluid into them. The enlargement of the tracheæ may also be observed in the *antennæ* (§ 88), which, just before the change were coiled up within the sides of the head, but are now extended along the sides and abdomen.

396. The full development of the respiratory apparatus only takes place, however, after the last metamorphosis; when the wings become fully distended with air, and prepared for flight by the active respiratory movements of the body; and the expansion of the pulmonary sacs proceeds to a greater extent. It may frequently be noticed that for some hours or even days after the perfect Insect has emerged from the pupa state, it makes no effort to fly, but remains in almost the same torpid condition with that it has quitted; when stimulated to move, however, it makes a few deep inspirations, its wings rapidly become fully expanded, and it soon trusts itself in the element which was intended for its habitation. The pulmonary sacs sometimes attain a very large size, and communicate with each other so freely as to appear like continuous cavities. This is well seen in Fig. 21, which exhibits the respiratory apparatus of the abdomen of the Humble-bee; and in Fig. 146, which shows that of the *Scolia hortorum*. They vary considerably, however, in different species and tribes; being usually most developed in those insects that sustain the longest and most powerful flight, which are generally those whose larva condition has been most imperfect, and in which there has been originally

* Newport on the Respiration of Insects, Phil. Trans. 1836.

no appearance of these enlargements. They are almost entirely absent in the insects destined to live upon the ground; or in them are little larger than the slight expansions found in the early conditions of such as undergo no complete metamorphosis. There can be little doubt that one use of these cavities is to diminish the specific gravity of the Insect, and thus to render it more buoyant in the atmosphere; but it would not seem improbable that they are intended to contain a store of air for its use while on the wing, as the spiracles are at that time closed, so that none can enter from without.

397. The various provisions which are made for the respiration of such insects as inhabit the water are of a nature too interesting to be passed by. In those aquatic Larvæ which breathe air, we often find the last segment of the abdomen prolonged into a tube, the mouth of which remains at the surface while the body is immersed. The larvæ of the gnat may often be seen breathing in this manner, which calls to mind the elevation of the trunk of the elephant when crossing rivers that entirely conceal his head and body. Sometimes this air-tube, which is to be regarded as a prolonged spiracle, is several inches in length, and its mouth is furnished with a fringe of *setæ* (or bristles), which entangle bubbles of air sufficient to maintain respiration when the animal descends entirely to the bottom. The large tracheæ proceeding from this tube convey the air through the body in the usual way. Most aquatic Larvæ which are unpossessed of such an air-tube, have their spiracles situated only at the posterior extremity of the body, and may be seen apparently hanging from the surface, whilst taking in the necessary supply. All perfect insects being adapted to aerial respiration only, many curious contrivances may be witnessed among such as inhabit the water, for carrying down a sufficient supply of oxygen to aerate their blood whilst under the surface. Some enclose a large bubble beneath the *elytra* (wing-cases) which, not being closely fitted to the exterior of the body, leave a cavity into which the spiracles open. Others have the whole under surface of the body covered with down, which entangles minute bubbles of air in such large quantity as to render the insect quite buoyant, and to oblige it to descend by creeping along the stem of a plant, or by a strong muscular effort. A very beautiful contrivance for a similar purpose is that of the diving-spider, which remains for a considerable period under water by means of a reservoir that it constructs of silken thread agglutinated together, open at the bottom like a diving bell, and attached to neighbouring stones or plants, and which it gradually fills with air by carrying down successive bubbles beneath its body. In this habitation it spends the winter in a state of partial torpidity, and the quantity of air it has enveloped in this curious manner is sufficient to maintain its respiration.

398. There are some Larvæ, however, more particularly adapted to

aquatic respiration by the development of the tracheal system externally into branchial plates or tufts, the object of which is not so much to carry the circulating fluid into contact with the water, as to absorb from that element the air which it contains, and which is then carried into the internal respiratory apparatus. Sometimes the membrane which covers the tracheæ, and which is a prolongation of the external surface, is continuous, so that the gills have a foliaceous appearance like that of the wings; but, in other cases, it is divided, so that the branchiæ more resemble the filamentous tufts of the Nereis. Their position is constantly varying; sometimes they are attached to the thorax, sometimes to the abdomen, sometimes even situated within the intestine; but in every case they have an important relation with the movements of the animal, and are frequently the sole organs of progression with which it is furnished. Thus, the sudden darting motion of the Larvæ of the *Libellula* (dragon-fly) is caused by the violent ejection from the intestine of the water which has been taken in for the supply of the gills it contains, whence it is received into the tracheal system. A very little examination into the structure of the wings will show that it is essentially the same as that of the expanded gills of aquatic larvæ; each consisting of a prolongation of the superficial covering of the body over a system of ramifying nerves or ribs, which are principally composed of tracheæ in connection with those of the interior of the fabric. Hence Oken followed by Blainville, termed the wings *aerial gills*,—an idea which, however ridiculed by succeeding writers on Entomology, will be found to be supported by the strictest analogies in structure, situation, and development. It is only by taking an extensive view of comparative structure that we can have any hope of arriving at accurate results; and great care is necessary to dismiss from the mind all prejudice in favour of a particular organisation as a standard or type of the rest. If we suppose an Entomologist to form his views of the structure of Animals in general from that of the Articulata, he would expect to find the wing of a bat or bird constructed on the model of that of an insect. Yet he would not be acting more absurdly in maintaining that this organ is developed out of the respiratory system in Vertebrated animals (especially considering its remarkable connection with this system in birds), than many entomologists who have been led, by their previous acquaintance with other types of structure, to consider the wing of an Insect as a modification of its leg (§ 194, *note*).

399. In the CRUSTACEA, the respiratory organs are universally adapted for an aquatic medium, and are consequently developed in the form of gills, which are usually placed on the under surface of the body, and connected with some very moveable parts, as there is not yet any special means adapted for propelling currents of water over them. The different orders of this class, however, exhibit so many interesting gradations of development of the respiratory system, that they can scarcely be overlooked

in a sketch like the present;—especially since these gradations exactly correspond, as Milne Edwards has admirably shown, with the transitory forms which each individual of the higher species presents in the progress of its development. In the lowest tribes no special aerating surface is evolved, nor do any of the other organs appear to undergo such modifications as would fit them for assisting in the discharge of the function; it must be concluded, therefore, that the process of respiration is carried on by the whole exterior of the body. In other orders, again, the last joints of the legs are flattened out into a surface which is soft and vascular, and which, by its action upon the water, appears calculated to facilitate the influence of the air upon the nutritious fluid. Proceeding higher, we find a particular portion only of the extremity devoted to respiration; but this is developed to an increased extent, and the water in contact with its surface is incessantly renovated by currents set in motion by the abdominal members. The next stage in the specialisation of this function is the restriction of the branchial apparatus to the abdominal members, which are entirely devoted to it, and cease to have other uses. In a still higher order, the gills have assumed more of the character which they present in Fishes and some Mollusca; the laminated or leaf-like form which they at first possessed, having given place to one in which the surface is greatly extended by minute subdivision into delicate filaments.

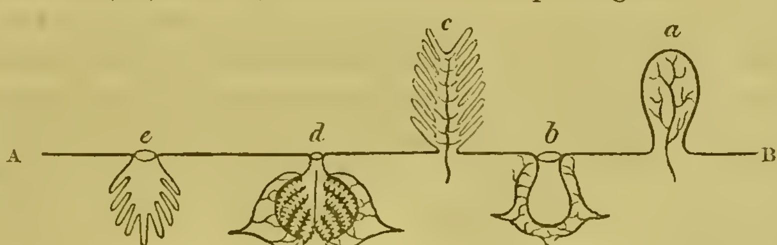
400. The most developed form of respiratory apparatus possessed by Crustaceans is that which exists in Crabs, Lobsters, and other Decapods. In this order not only is the function thrown upon particular organs created expressly for the purpose, but these organs are lodged and protected within especial cavities, and the renewal of the water necessary to their operation is secured by the motion of distinct appendages. These cavities are formed by a reduplication of the external tegument, and are provided with two orifices, one for the introduction and the other for the expulsion of the fluid. In those Crustacea which are adapted to live for a time on land, these orifices are very small, so that a trifling amount of evaporation can take place from them; and it appears that in all species the gills can be subservient to aerial as well as to aquatic respiration, provided their surface is kept moist,—the asphyxia of the animals in a dry atmosphere being due to the desiccation of the membrane, and its consequent unfitness for the performance of its functions. There are other species which not only live habitually out of water, but are infallibly drowned if kept long immersed in that fluid. These are the *land-crabs*, which are esteemed among the greatest delicacies of the West Indian Islands, and are sometimes regularly fattened for the table. The membrane lining their branchial cavities is sometimes disposed in folds capable of serving as reservoirs for a considerable quantity of water, and sometimes presents a spongy texture equally well adapted for storing up the fluid

that is necessary to keep the organs of respiration in a state of humidity required for the performance of their functions. Land-crabs are never known to remove far from damp situations; and this humidity may be either derived from the atmosphere, or may be secreted, as in higher animals, from the circulating fluid. It can scarcely be doubted that the spongy lining of the branchial cavity in these Crustacea is peculiarly subservient to aerial respiration; and it appears owing to the check given to its activity that the land-crabs are drowned when plunged under water. A more highly-developed form of this type of respiratory system is found in the next class.

401. The stages in the development of the branchial apparatus of the *Astacus fluviatilis* (river-crab) have been so beautifully traced by M. Milne-Edwards in connexion with the various forms of the same in adult species of different tribes, that it seems advantageous to notice them here for the sake of ready comparison, rather than to defer the account of them to the general description of the progressive evolution of the system in the embryo of higher animals. At the earliest period of embryotic life, no trace of branchiæ can be discovered; but when they are first evolved, during the process of incubation, they consist of simple laminated expansions, occupying the situation of the extremities of the maxillary appendages; these soon subdivide, and one part assumes a cylindrical form, and seems no longer to belong to the apparatus,—whilst branchial filaments begin to appear on the other, which are subsequently prolonged into complete gills. During this interval the thoracic extremities have made their appearance, and they also become furnished with branchial appendages. At a subsequent time, a narrow groove or furrow is seen along the under edges of the thorax, the margins of which, in no long period, are prolonged so as to meet each other and enclose the gills; openings being left for the entrance and exit of water, which are at first large, but subsequently become contracted to the proper size. It is thus evident that the lining membrane of the cavity, as well as that which covers the filaments of the branchiæ, is but a prolongation of the external tegument. We cannot avoid perceiving in this conformation, a transition from the branchial to the pulmonary form of the respiratory apparatus; a transition which is still more evident in the structure of the next class.

402. In the lower tribes of the ARACHNIDA, which approximate most nearly to the Insect type, such as the *Acari* (cheese-mite, &c.) the respiratory apparatus is constructed on the plan which prevails in that class; being composed of a system of tracheæ, ramifying through the body, and opening externally by stigmata. In the more perfect forms, however, such as the *Spider*, *Scorpion*, &c., the circulating system is more developed, and there is no longer occasion for such universal aeration of the individual parts, that of the nutrient fluid being sufficient. Accordingly the respiratory apparatus exists in a more concentrated state, which ap-

proximates nearly to that which has been described as possessed by the higher Crustacea; but, being adapted for aerial respiration only, it must be regarded as belonging rather to the pulmonary than to the branchial system. The stigmata in these animals, instead of opening into a prolonged set of ramifying and anastomosing tubes, enter at once into distinct sacs, disposed along the sides of the abdomen, to which the air has therefore ready access. The interior of these cavities is not smooth, however, like that of the pulmonary sacs of Insects, but prolonged into a number of duplicatures or folds; these lie close to each other like the laminæ of gills, and may be regarded either as analogous to them, or as rudiments of the partition of the cavity into minute cells, as in the lungs of higher animals. From these analogies to both classes of organs they are denominated by Audouin *pulmonary branchiæ*. The following figures will serve as a *plan* of the transition which is thus effected between one form of respiratory apparatus and another. At *a*, is seen the character of the simple foliaceous gill, which is evidently a mere *external* prolongation of the general surface, A, B; at *b*, a similar *internal* prolongation or reflexion,



forming the simple pulmonary sac of the leech or earthworm; *c* represents a gill formed by the minute subdivisions of the surface into filaments, so that it is greatly extended, as we find it in fishes; and *d* shows a similar extension of the internal surface by the partition of the cavity, (by which is effected, within a small space in the lungs of Vertebrated animals, that which the economy of the Insect condition required to be performed by an apparatus of much greater extent); lastly, at *e* is shown a plan of one of the respiratory cavities in the Crustacea, or of the pulmonary branchiæ of the Arachnida, exhibiting the transition already described, in the location of the gill-like processes upon the concave walls of a cavity formed, like that of the lungs, by an internal prolongation of the tegumentary surface.

403. In this slight sketch, then, of the development of the organs of respiration in Invertebrated classes, it will be observed that, whilst the entire covering of the animal is subservient to this function in the lowest tribes, portions of the surface specially modified for the aeration of the blood are found in the higher: these being disposed, according to the medium which the animal is destined to inhabit, in the form of gills or pulmonic cavities; and situated in the most convenient position for receiving the fluid, and for submitting it to the influence of the surrounding

element. Although amongst some of these animals the *branchial* apparatus reaches nearly the highest development which it attains under any circumstances, we only observe the sketch, as it were, of the *pulmonary* organs of the higher Vertebrata, which never lose their diffused character in the classes we have been considering. In no case do the respiratory organs communicate with the mouth, which is an organ solely appropriated, in these lower tribes, to the reception and subdivision of the food; and it may also be remarked that the movements by which the aeration of the blood is assisted are, in most cases, those of the body at large.

404. Amongst the VERTEBRATA we observe a similar diversity of form in the respiratory organs to that which the inferior classes have presented to us; and the differences in the general economy of the system, with which the amount of the function is connected, are manifested in even a more striking degree. In the slow-moving Reptile, as in the Mollusca, where the respiration is feeble, it may be suspended for a time without inconvenience; but to the active inhabitants of the air, Birds as well as Insects, in whom this function is necessarily performed with great energy, its suspension is quickly fatal. If a bird be kept in a limited quantity of air until it ceases to respire, and we then place successively in the same atmosphere, a dormouse, a frog, and a snail, each of these animals will continue to breathe for some time in an atmosphere which its predecessor had vitiated too much to continue to support its own respiration.

405. Although the respiratory apparatus in FISHES retains the type which characterised it in the inferior aquatic classes, it undergoes great increase both in extent and importance. In order to keep up with the rapid advance in the development of the other systems, the respiration requires to be conducted, though by means of an aquatic element, with great velocity and effect. For this purpose it is not sufficient that fishes should have merely filamentous tufts hanging loosely at the sides of the neck; but it is requisite that they should have the means of rapidly and constantly propelling large streams of water over their surface, and of forcing the whole blood of the system through the respiratory apparatus, to be submitted to the action of the air that is contained so scantily in the water. The former of these ends is effected by the connexion of the gills with the cavity of the mouth, the muscles of which send a rapid current of water through the branchial passages; and the latter, by the alteration in the position of the heart, which is placed so as to affect the respiratory organs previously to the system at large (§ 309). The gills in most fishes are disposed in fringed laminæ, the fibres of which are set close together like the barbs of a feather (Fig. 149), and attached on each side of the throat in double rows, to the convex margins of four or five long bony or cartilaginous arches which are very similar to the ribs.

The extent of surface exposed by these gills is very great; Dr. Munro computed that in the skate it is at least equal to that of the human body. In the osseous fishes, the gills are concealed by a valvular covering, called the *operculum*, which allows free exit to the water impelled through the mouth. In the cartilaginous fishes, the gills are more completely enclosed, and the water which passes over them finds its way out through five small openings on each side of the neck, which are called *branchial openings* (Fig. 148); these, as will be hereafter seen, may be detected at an early period of the development of all higher animals, not excepting man himself. During the embryo condition of both of the principal divisions of Fishes, the gills may be seen hanging loosely from the back part of the neck; for, in osseous fishes, they have attained considerable development before the prolongation of the integument has been formed into the valve which covers them; and in the cartilaginous fishes, the branchial openings are at first large, and the filaments of the gills are prolonged much beyond them,—other filaments also, which subsequently disappear altogether, being produced from their edges.

406. In considering the respiratory organs of Fishes, the air-bladder must not be omitted, this being now generally regarded as the rudimentary form of the complex lungs of the higher Vertebrata. In many Fishes, as in the embryo of Mammalia, it is a simple shut sac, placed along the middle of the back; in others, it has a division of its cavity by one or two membranous partitions. This air-bag usually communicates with some part of the alimentary canal near the stomach, by means of a short wide canal termed the *ductus pneumaticus;* but sometimes, as in the *sword-fish*, it has no manifest opening, and we find it connected with a glandular and highly vascular organ, which has been supposed to secrete the gas that it contains. The true character of the structure is most remarkably shown in the *Lepidosteus* or bony-pike of the North American lakes (§ 81). This curious fish, which presents many points of approximation to the lizard tribe, has the air-bladder divided into two sacs that possess a cellular structure,—the trachea that proceeds from it opening high up in the throat, and being surmounted with a glottis. As many fishes are known to swallow air and eject it as carbonic acid gas, it would scarcely seem impossible that where a communication exists between the alimentary canal and the air-bladder, the latter organ is concerned in the change: for the process of respiration is performed by an action resembling swallowing in frogs and other Amphibia which possess no ribs or diaphragm; and in those curious species which are modified for both aerial and aquatic respiration, the lungs are scarcely more highly-organised than the air-sacs of the Lepidosteus.

407. The uses of the air-bladder in those fishes which possess no *ductus pneumaticus* are involved in some obscurity. That it is not immediately connected with the function of respiration appears sufficiently

evident; and this seems one of the instances, of which many might be pointed out both in the vegetable and animal kingdoms, where the rudimentary form of an organ that attains its full development in other classes, is adapted to discharge some office quite different from that to which it is destined in its perfect state. The gas which it contains is composed of the same elements as atmospheric air, namely oxygen, nitrogen, and carbonic acid; but these are mixed in proportions that are very liable to variation. It has been said that oxygen is deficient in the contents of the air-bladder of fresh-water fishes, and is predominant in that of fishes which remain at considerable depths in the sea. This organ is altogether absent in fishes accustomed to remain at the bottom, and whose movements are slow; whilst it is of large size in those remarkable for vehement and prolonged movements, especially in Flying-fish of various species. It is generally supposed that the fish is enabled by means of the air-bladder to alter its specific gravity, by compressing the bag or permitting its distension; but experiment shows that, after the organ has been removed, a fish may still retain the power of raising or lowering itself in the water.

408. The transition which has already been described, as occurring between the class of Fishes and that of REPTILES, and as being manifested, not only in the permanent and complete forms, but during the progress of the development of individual organs, is nowhere more beautifully indicated than in the respiratory apparatus. All of the order *Batrachia* (otherwise called Amphibia), when young and imperfect, inhabit the water solely, and are in fact *pro tempore* fishes. Their organs of respiration are of course formed on the aquatic type, consisting of branchiæ; and, in their early development, they undergo the same change with those of fishes. In all instances they are at first external, hanging like tufts from the neck; and this state continues in the Proteus, Siren, and other species of the family of *perennibranchiate* amphibia (which retain their gills through life). In those, however, whose development proceeds further, as frogs, salamanders, &c., they are subsequently more or less enclosed by a fold of the skin, which forms a membranous valve, analogous to the bony operculum of fishes. In frogs, the branchial cavity thus formed is closed completely on the right side, and the water which passes into it is ejected through the opening that remains in the left. As the tadpole advances towards the final change which is to convert it from a fish into a reptile, the gills entirely disappear, and lungs are developed, by which it breathes for the remainder of its life. These lungs are not, however, minutely subdivided like those of Birds or Mammalia; a large part of their cavity is simple; and the appearance of partitions is almost restricted to the top (Fig. 150). It appears as if, in the family of perennibranchiate amphibia, the development had been checked just at the period of the transformation; for we find their *permanent* form exactly

corresponding with that which is *transitory* in those that undergo a complete metamorphosis, and resembling that which has been artificially rendered permanent in the latter by the due regulation of the vital stimuli (§ 183). It is not a little curious that the habitation of the least-developed of these animals, the *Proteus*, subjects it to exactly the same conditions as those by which Dr. Edwards found that he could retard the development of the frog; and, until analogous species were found elsewhere, it was believed to be the Larva of some more perfect Reptile.

409. The members of this family of *Perennibranchia* (which are the only true *amphibious* animals) possess lungs more or less developed; those of the Proteus being very similar to the air-bags of fishes, whilst those of the *Siren* exhibit some degree of partition into cells. The tube by which they open into the mouth bears greater analogy to the ductus pneumaticus than to the trachea of higher animals, being simply membranous without an appearance of rings; and the glottis in which it terminates is a mere slit in the throat. Thus, the transition from the simple closed sac of fishes to the more complex subdivided lung of the frogs and land-salamanders is perceived to be very gradual; whilst, at the same time, the point of connexion between the respiratory cavity and the alimentary tube may be observed to ascend, by similar gradations, from the stomach or some neighbouring part to the œsophagus, and at last to the mouth. Although all the animals which retain their gills at the same time that they acquire lungs, are more or less adapted both to aerial and aquatic respiration, the relative degree of the two varies with the comparative development of their organs. Thus, in the Siren, the pulmonic respiration is more extensive and important than the branchial; but the reverse is the case in the Proteus. In taking leave of respiration by gills, it must not be forgotten that, even in the most developed condition of their structure, these organs are covered with vibratile cilia of precisely the same character as those which seemed to be the only organs connected with this function in the lowest and simplest animals. In both cases, however, their purpose would seem to be the same, viz., to create currents over the surface on which they are fixed, which shall constantly renew the stratum of fluid in apposition with it. In the larva condition of the Amphibia, they are not confined to the gills, however, but act over the whole body; and, in the adult, the general surface appears peculiarly connected with the function of respiration, the soft moist skin being an excellent medium for the exposure of the blood to the air. Experimental proofs of the degree in which the general surface of Fishes and Batracians may be regarded as sharing in the process of aeration, will be hereafter given (§ 422).

410. In *Serpents*, we usually find a long cylindrical sac, only divided into cells at its upper part, and generally extending along the tail; in

some genera, however, this sac is double; and where there is only one, it is that on the right side which is developed, the other remaining in its rudimentary state. From the great capacity of the respiratory sac, the mobility of their ribs, and the power of their intercostal muscles, Serpents are capable of rapidly inspiring and expiring a large quantity of air, by which the want of an extensive surface is compensated, and energy is imparted to their muscular exertions. It is the prolonged expulsion of the air after the lung has been fully inflated, that gives rise to the continued hissing sound by which these animals sometimes alarm their prey. In the aquatic Serpents, the large volume of air contained in the body serves to render it buoyant, and at the same time supplies the wants of the animal during a prolonged immersion. Serpents may be regarded as representing, in their general conformation, the lower Articulated classes among Vertebrata, whilst Birds evidently typify the Insect tribes. The prolongation of the lung through nearly the whole extent of the body, and its low degree of development, indicated by its almost entire want of cellular subdivision, forcibly remind us of the pulmonary sacs of the Leech or Earthworm.

411. In the *Saurian* reptiles, we still find a very imperfect subdivision of the pulmonary sacs; but they are equally developed in both sides of the body. In the lower genera of this order, there is scarcely any appearance of cells; but when we have advanced upwards to the Crocodile, we find the lungs, though externally small, subdivided to a great degree of minuteness by internal partitions; and we also find a rudimentary condition of the diaphragm, which is entirely wanting in all the inferior genera, the lungs frequently extending in them through the whole trunk. In the *Chameleon* for instance, as well as many other Lizards, the lungs extend far beneath the skin; and, by their fulness or emptiness of air, give rise to the plump or lean appearance, either of which these animals have the power of assuming by the simple processes of inspiration or expiration. It is not a little curious that in the Crocodile are found two openings, leading from the surface to the interior cavity of the abdomen, which is lined by the peritoneum. This structure is evidently similar in character to that which has been described in the Holothuria (§ 390); whether it is adapted to the same purpose is not yet fully ascertained. It has been supposed by Geoff. St. Hilaire, that the superior energy of the Crocodile when immersed in water is due to the penetration of that fluid into the abdominal cavity, and the consequent conversion of the peritoneum into an additional respiratory surface. Whether this be correct or not, it is worthy of notice that the sternum is prolonged over the front of the abdomen, and the sides fortified with ribs like the thorax; a structure of which the indications are readily traced in the *linea alba* and *lineæ transversales* on the abdominal muscles of Mammalia. The structure of the lungs in Turtles and other *Chelonia* is very similar to that exhibited by the higher lizards; the sacs

are very capacious and have few subdivisions; and they materially assist, by the quantity of air they contain, in buoying up the heavy trunk of these animals when sailing on the surface of the water. The Chelonia, like the inferior Reptiles, are obliged to distend the lungs by a process resembling swallowing; the diaphragm being nowhere developed in a sufficient degree to be capable of producing *active* inspiratory movements. Thus, however paradoxical it may appear, a reptile can be prevented from respiring by holding its mouth open.

412. The respiratory apparatus of BIRDS is intermediate in the perfection of its development between that of the Reptiles and that of the Mammalia. In this class, as in Insects, it extends through a great part of the body; large sacs connected with the lungs being contained in the abdomen, and even continued beyond the cavity of the trunk, as under the skin of the neck and extremities.* Even the bones are made subservient to this function; for though at an early period they possess a spongy texture, like those of the Reptiles, and are filled with thin marrow, they subsequently become hollow, and their cavities communicate with the lungs; in the aquatic species, however, the original condition is retained through life. In those Birds of which the bones are thus permeated by air, the trachea may be tied and the animal still continue to respire by an opening made in the humerus or even the femur. The lungs are confined, as in Tortoises, to the back part of the cavity of the trunk; they are of a spongy texture, but much less minutely subdivided than those of Mammalia. No diaphragm exists in Birds, except in the Ostrich, which forms a transition to the class Mammalia; and, from the manner in which the lungs are connected with the walls of the chest, the state of distention is the natural or passive condition, and

* Various surmises have been formed on the particular uses of these air-sacs in the economy of the bird; and it does not seem improbable that, besides contributing to the function of respiration by the extension of surface they afford, they have some subsidiary purposes. One of the most evident is that of rendering the body specifically lighter, as in Insects; and this will be obviously assisted by the great heat of the system, which rarifies the contained air. Again, the distension of the air cells assists in keeping the wings outstretched; as is shown by the fact that inflation of those situated in the neighbourhood of their muscles is followed by their expansion; this must be a most important economy of muscular action in birds which hover long in the air. Their evident analogy to the pulmonary sacs of insects is confirmed by their relatively larger dimensions in birds of long continued and rapid motion, than in the slow-moving tribes which are almost confined to the earth or waters. It has been remarked in addition that "the same air which exerts its renovating influence upon the blood, supports all the more delicate structures which it reaches and surrounds, as a cushion of the most perfect softness and elasticity; so that by the most rapid motion, and the most violent twitches which the body receives in the changes and turnings of that motion, there can be no concussion of the parts more immediately necessary for the life of the birds." It would scarcely seem improbable that the large air-cells which are found extending beneath the integument of the whole body, especially the under surface, of the Pelican and Gannet, serve to deaden the concussion which the system must experience when the bird, after raising itself to considerable height in the air, lets itself suddenly fall upon the water in pursuit of its finny prey.

the act of respiration is forced. It is beautiful to observe that in Birds, as in insects, the great extension of the respiratory surface is given by a simple increase in the capacity and prolongation of the sacs, and not by that concentration of it into a small bulk which is effected by the minute partitioning of their cavity, and which indicates the highest form of the respiratory organs. Another analogy to the character of the respiratory system of insects is this: in insects, the whole of the aeration is effected by bringing the air in contact with the blood actually circulating through the system; whilst, in the higher air-breathing animals possessed of a more centralised apparatus (whether consisting of lungs or gills), the blood is transmitted through it by a special adaptation of the vascular system, in the intervals of its circulation through the body. In Birds is presented a curious adaptation of the latter more elevated type to the conditions of their existence; for, whilst the air introduced into the lungs acts upon the blood transmitted by the pulmonary vessels, that which fills the air-cells and cavities of the bones comes into relation (as in Insects) with the capillaries of the system at large.

413. The respiration of MAMMALIA is not, like that of Birds, extended through the system, but is restricted to the lungs; and as a perfect diaphragm is now developed, which completely separates the thoracic from the abdominal cavity, these organs are confined to the former. Although their bulk is proportionally so much smaller than that of the pulmonary sacs of birds, or even reptiles, the actual amount of surface over which the blood is exposed to atmospheric influence, is beyond comparison larger, owing to their very minute subdivision into cells (Figs. 151, 2). The want of capacity, too, is compensated by the active movements of inspiration and expiration, which constantly and most effectually renew their contents; for, by the contraction of the diaphragm, and the elevation of the ribs, the cavity of the thorax is greatly enlarged, and the air rushes into the lungs to fill up, by distending them, the vacuum thus created; and the diaphragm being relaxed, and pushed upwards by the contraction of the abdominal muscles upon the contained viscera, and the ribs being at the same time depressed, the cavity of the chest is again diminished and the contents of the lungs expelled. It has been ascertained by experiments made for the purpose of discrimination between the lungs which have been distended by natural inspiration, and those which have been artificially inflated (a point of much importance in criminal enquiries as to Infanticide), that in the former case a much more minute injection of the ultimate air-cells takes place, than in the latter; and that while portions of the lung which have been artificially inflated may be compressed in such a manner as to sink in water, the air cannot be expelled in a similar manner from lungs which have once breathed naturally, without their structure being entirely broken down. This fact serves to show the superiority of a mode of respiration like that of the Mammalia over the deglutition of air prac-

tised by Reptiles. The lungs are greatly developed in all the more powerful Mammalia, as in the carnivorous species; but they are comparatively smaller in their extent of surface in the feeble and inferiorly-organised herbivora. The varieties of these organs presented by the different orders of quadrupeds relate chiefly to their exterior divisions, and to their greater or less capacity; the plan of structure being nearly the same in all. It is interesting to remark, however, that in every case the lungs are largest on the *right* side; we have seen that in Serpents, where only one lung is developed, it is also the right; and even in the air-breathing Gasteropoda the pulmonic cavity is on the same side. This fact seems to have a connexion with the superior energy of the members on the right side, which is by no means confined to man, or acquired by habit, as some have supposed.

414. We observe in the respiratory system of Mammalia the highest degree of connexion between the organic and animal functions which is any where exhibited. The mere act of the aeration of the blood is as completely independent of the *animal* powers in them, as in the simplest beings in this kingdom, or as the corresponding process in plants. But to give sufficient opportunity for the energetic performance of this function which is required by the higher animals, an immense extension of surface becomes necessary; and as this extension obviously could not be produced, consistently with the other conditions of their existence, by a proportional increase of their external superficies (as in plants), it is obvious that some means must be provided for constantly renewing the air in contact with the delicate partitions of the minutely-divided cells of the internal organs. This is accomplished by the respiratory movements, which are performed by the muscular and nervous systems; but these are not more immediately connected with the aeration of the blood, than is the action of the heart which propels that fluid to the lungs (§ 212, 3).

415. The preceding sketch of the progressive evolution of the respiratory system in the animal scale may seem to have been extended to a disproportionate degree; but fuller details have been entered into on this subject than have been elsewhere given, since it is one peculiarly adapted to furnish illustrations of the general laws which have been previously enunciated. The function of aeration is one capable of being particularly well defined; and, as any structure adapted to it becomes at once a respiratory organ, there can be no difficulty in tracing the analogies between the corresponding parts in different animals, except in cases where they have undergone a metamorphosis for the sake of being adapted to some other purpose, as the wings of Insects, or the swimming-bladder of Fishes. It has been seen that the fundamental character of the respiratory organs is everywhere the same, however different their external form; and that it is only the disposition of their parts that is varied in accordance with the circumstances in which their function is to be performed. The pro-

gressive specialisation of the function has been traced in ascending the series, by marking the evolution of a particular apparatus for its exercise, and the restriction of it to that apparatus; in no instance has any sudden change in character been witnessed; but, in the classes adjoining those in which a new organ was to be introduced, has been found some adumbration of it; yet even where the function is most highly specialised, the general surface is found to retain in some degree its participation in it, as will be presently shown (§ 422). We shall now briefly trace the evolution of the respiratory apparatus in the embryo of the higher Vertebrata; reserving, as before, the account of the earliest changes in the ovum to a future period (CHAP. XIII.), and leaving until that period the description of the organs which are peculiar to the fœtal condition, and which serve only to assist in the conversion of the nutriment supplied from the parent system, as during the germination of seeds.

416. At about the third day of the development of the chick, four pairs of clefts or transverse slits are observable behind the mouth, in the situation of the branchial apertures of fishes; and at the same time, the branchial vessels are developed from the aorta, as already described (§ 325). One of the apertures is intermediate between each pair of vascular arches, just as in the gills of fishes and tadpoles. Nothing like branchial tufts, however, are developed; and the appearance described is very transitory, the vessels changing their direction and condition within two days. The development of perfect gills would have been useless, as the animal has not to maintain its own existence like the tadpole, but subsists, until the time of the perfect evolution of its respiratory system, upon the store of aliment furnished by the parent. It is evident, however, that the history of this evolution is so far the same as in Reptiles and Fishes. The lung first appears as a simple closed sac lying at the posterior and lowest part of the thorax; it soon becomes bifid, and presents a cavity, which does not, however, for some time communicate with the intestinal tube, the trachea and bronchi being last developed. The history of the evolution of these organs in the Mammalia is precisely analogous. It is usually at about the sixth of the period of uterine gestation that the rudiments of the branchial apparatus are seen, as marked by the shortness and thickness of the neck, the penetration of the sides of the pharynx by the branchial clefts, and the division of the aorta into vessels corresponding in number and distribution with the branchial arteries of fishes. These general features have been observed in the embryos of most orders of Mammalia, not excepting man himself; and they are probably common to all. A few days after the appearance of the fifth arch, which is the last developed, the neck begins to elongate, the apertures are closed gradually on the outside, while the vascular arches undergo those changes by which the permanent arterial branches arising from the heart are formed. The lungs in Mammalia are developed

much in the same manner as in Birds. They are not discernible before the period when the branchial apertures begin to close; a single mass is first perceived, which is soon divided into the rudiments of a right and left lung by a longitudinal groove; and the trachea and bronchi are subsequently developed, as in birds. Scarcely a more beautiful illustration of the Unity of Design manifested in the creation of different classes of animals could be adduced than this hidden but not obscured correspondence; and the inferences to be drawn from it could hardly be more admirably expressed than in the subjoined passage from the eloquent pen of Professor Powell.* Nor is the analogy confined to animals alone; for it is impossible to compare the stages of the evolution of the perfect respiratory apparatus in the higher forms of the two kingdoms, without being struck with their essential correspondence. In the flowering plant we have seen a temporary respiratory organ, the *cotyledon*, first developed, just as the branchiæ of a tadpole; and disappearing altogether when the evolution of the permanent aerating apparatus renders it unnecessary. And just as the system which is the permanent one of the lower tribes of animals, is transiently indicated in the early development of the higher, will it subsequently appear (§ 526) that the foliaceous expansions of the inferior stemless Cryptogamia are to be regarded as the analogues of the cotyledons of flowering plants, and thus, like the gills of aquatic animals, continue to perform their functions during life in a degree adapted to the wants of the system.

417. That which has been said of the correspondence of the essential structure of the respiratory apparatus, through all its varieties of external form, will apply with equal truth to its function also; for, in whatever

* "In the gradual stages of the process here unveiled, we perceive organs bestowed apparently without discrimination as to the future destiny of the creature: adapted in many to no perceptible end; in fact positively useless and superfluous. All notion of final causes *seems* excluded; and all idea of adjustment to a purpose, violated. Even the suppression of a useless organ, and the substitution or super-induction of one which is useful, seems a circuitous and unnecessarily complex process of obtaining the end ultimately accomplished. But when we look at the *regularity of the system* on which all this is planned; when we consider that these useless or abortive organs are, in all cases, constructed on one simple model; when we observe the precise order in which they disappear, exactly in accordance with the destined difference of function in the different species; when we trace the undeviating scheme on which the new modifications are respectively super-induced; when we regard the determinate scale, according to which the whole process is unalterably carried on;—then we shall be urged with an increasing and accumulating force of conviction to the conclusion that all this arrangement, however apparently complex, is in reality an astonishing instance of conformity to laws of the most recondite simplicity: that every step in the process, however apparently superfluous, is in strict accordance with a great principle of uniformity: that every stage in the transformation, however, in first appearance, destitute of a direction to a purpose of utility, yet if it answer no other, has its direct application in filling up a place in the universal harmony and incomparable Unity of design, which pervades all organised nature. The very singularity of the provision, well considered, evinces the enlarged preservation of analogy: the very objection and difficulty of the case is converted into an evidence in favour of the argument from symmetry." Connexion of Natural and Revealed Truth, p. 145.

tribe of animals the changes composing it have been investigated, they are found to be of a very uniform character. The object of these changes appears to be in all instances the liberation of carbon from the blood in a gaseous state, the communication to it of oxygen, and the exchange of nitrogen on one side or the other. It will be more convenient to enquire into the particular character of these changes in the distinct form in which they are presented to us in the higher animals, before proceeding to investigate their more obscure manifestations in the inferior tribes. These changes may be examined either in the circulating fluid, or in the air to which it has been exposed.

418. The most obvious difference between the fluid brought to the lungs for aeration after passing through the capillaries of the system, and that which has undergone the process,—or in short between venous and arterial blood—is its colour, which is dark purple (sometimes called black) in the former, and bright red in the latter. The alteration in colour may be produced by agitating venous blood with oxygen, or even by exposing it for a time to the atmosphere; in the latter case, however, the surface only acquires the arterial tint. The bright scarlet colour may also be given by the admixture of neutral salts; whilst the addition of acids renders it still darker and prevents the change. When venous blood is placed under the vacuum of an air-pump, a small quantity of carbonic acid gas is given out; but a larger amount, sometimes one-sixth of the whole volume, is evolved when the blood is agitated with atmospheric air, hydrogen or nitrogen. Gas may be extracted also from arterial blood by means of the air-pump, and this is found to consist of a larger proportion of oxygen. From the experiments of Magnus, the latest and most satisfactory on the subject, it appears that the oxygen in arterial blood amounts to about $\frac{1}{3}$ or $\frac{1}{2}$ of the quantity of carbonic acid which it contains, whilst in venous blood it bears the proportion of at most $\frac{1}{4}$ and often only $\frac{1}{5}$. The relative quantity of nitrogen is extremely variable. It appears that these gases exist in the blood in a state of solution, as atmospheric air is found in river and sea water; but it is not improbable that a feeble chemical union may take place between the oxygen and the colouring particles, since it appears to be by its action upon them, rather than by the extraction of carbonic acid, that the change of tint is produced.

419. The changes in the air which has been respired are capable of being examined with greater accuracy. They may be considered under four heads:—1. The disappearance of oxygen, which is absorbed. 2. The presence of carbonic acid, which has been exhaled. 3. The absorption of nitrogen. 4. The exhalation of nitrogen. The oxygen which disappears is usually more than is contained in the carbonic acid expelled, so that it must be actually absorbed into the system; and this we find to be especially the case in the lower classes of Vertebrata, and in all young

animals. The quantity varies in such proportion that it sometimes exceeds the third part of the carbonic acid formed, and is sometimes so small that it may be disregarded,—the difference depending, not only on the constitution of the species, but on the comparative degree of development, and on individual varieties among adults. This fact, which was first established by the admirable experiments of Dr. Edwards, explains the result obtained by Messrs. Allen and Pepys, who found the quantities of oxygen lost, and of carbonic acid produced, to be the same; from which it was inferred that the office of the oxygen was merely to remove the carbon from the system. These gentlemen took the greatest care to obtain accurate results; but their experiments were made on two species only,—man and the guinea pig. It is evident that the absorption of oxygen is necessary to communicate to the blood its powers as a vital stimulus; since animals do not long support life without it, although the usual quantity of carbonic acid be removed by other means. With regard to the production of carbonic acid, there is now quite sufficient evidence to prove that it is not generated by the contact of oxygen and carbon in the lungs, as was formerly supposed; since it is not only found to exist in venous blood, but in the products of the respiration of gases entirely free from admixture with oxygen. Such an experiment can only be performed on animals which can sustain for a time the absence of the stimulus of oxygen. That snails confined in hydrogen will generate carbonic acid was long ago shown by Spallanzani; but the recent experiments of Edwards, Müller, &c. upon frogs are more satisfactory, both from their superior accuracy, and from their freedom from the objection which might be raised against the others, on the ground of the low place of their subjects in the animal scale. It appears that, when confined in hydrogen, frogs will give out carbonic acid, for a time at least, as rapidly as in atmospheric air; and that the quantity generated in nitrogen is not much inferior.

420. These results are evidently conformable with the principles formerly stated as regulating the mutual diffusion of gases. Owing to its energetic reaction with carbonic acid (occasioned by its great difference in specific gravity) hydrogen removes it from the blood with greater force than any other gas; so that venous blood will give off carbonic acid when exposed to an atmosphere of hydrogen, even after it has been submitted to the exhausting power of a vacuum. It is obvious, however, that, for the continued generation of carbonic acid, oxygen must be supplied from without, as there is no superfluity of it in the system. The following, therefore, appears to be the history of the changes which the blood undergoes in its passage through the body. In the capillaries of the lungs it becomes charged with oxygen, which it carries into those of the system; in the course of the actions which there occur between the nutritious fluid and the textures it supports and stimulates, part of the oxygen

disappears and carbonic acid takes its place; the venous blood, therefore, returns to the lungs holding this in solution, together with the unabsorbed oxygen; and, in the capillaries of the lungs, the former gas is removed by the atmosphere, and replaced again by oxygen,—the interchange being entirely in accordance with the physical principles already stated.*

421. With regard to the absorption and exhalation of nitrogen, Dr. Edwards has shown that both these processes are constantly going on, but that their relative activity varies in different species and at different parts of the year. It appeared that an increase in the volume of nitrogen in the respired air took place in most young animals, and during the summer months; but that, in the autumn and winter, there is a considerable absorption when adult animals are employed. It is a curious question which is yet undecided, whether herbivorous animals absorb more nitrogen from the atmosphere than those of carnivorous habits; for, as nitrogen scarcely exists in vegetables, but enters largely into the constitution of all animal bodies, it does not seem unlikely that this is the source from which it is derived, when not contained in the food. It is probable, however, that no animal could exist long, if fed on purely unazotised principles.

422. The function of Respiration is not confined to the lungs, even in animals which possess them in their most developed form. The blood which circulates through the capillaries of the skin is aerated by communication with the atmosphere, wherever there is no impediment offered by the density of the tegumentary covering. In Amphibia, especially frogs, the cutaneous respiration is of such importance to the animal, that, if impeded by covering the skin with oil or other unctuous substance, death will take place almost as soon as if the lungs are removed; and the animal may be supported for a considerable time by it alone, if the temperature be not too high. In such circumstances it is found that carbonic acid is generated in an atmosphere of hydrogen, as by pulmonary respiration. In like manner, if Birds or Mammalia are enclosed in vessels out of which their heads protrude, carbonic acid will be found to replace a portion of the oxygen; and the same result has been obtained by the similar enclosure of a limb of the human body. Animals whose respiration is aquatic do not decompose the water they breathe, but merely abstract the oxygen from the air contained in it; for if one of this class be placed in a limited quantity of water, from which it soon exhausts the air, or in water from which the air has been expelled by boiling, it dies almost as soon as an animal whose respiration is aerial when placed in a vacuum. If, however, the surface of the water be in contact with the

* This view of the function of Respiration was given in a paper which the author published in the West of England Journal in the year 1835, as that which best accorded with the facts then known. It has been fully confirmed by subsequent experiments, especially those of Magnus, and he is most happy to find it now sanctioned by the eminent authority of Prof. Müller.

atmosphere, it will absorb air from it; and the life of the animal will be longer, the more fully the quantity thus obtained compensates for that which is consumed.

423. When a Fish, in a limited quantity of aerated water, has reduced the proportion of air until its respiration has become difficult, it rises to the surface and takes in air from the atmosphere; and, if prevented from doing so, it dies much sooner. The air thus taken in probably acts upon the lining membrane of the intestines; for, after being expelled, it is found to contain a large proportion of carbonic acid. The death of fishes when taken out of the water is partly due to the very rapid loss of the fluid of the body by transpiration (§ 435); and partly to the collapse of the gills, which prevents the air from having access to their surface, and to their desiccation, which incapacitates it from acting upon the blood beneath. Many Fishes are provided with a special apparatus for keeping the gills moist and free when exposed to the air, and such are able to live a considerable time out of water, especially in a humid atmosphere; thus, eels will leave their pools when dried up, and wind through the grass in search of water. The Doras of Guiana and the Hydrargyra of Carolina migrate in large bodies, under similar circumstauces, aud always direct themselves towards the nearest water, although they have no perceptible way of discovering it; aud the climbing perch of Tranquebar not only creeps upon the shore, but ascends the Fan Palm iu search of the Crustacea which constitute its food. The life of Fishes unprovided with any special modification for the purpose, may be prolonged for some time by raising the opercula and keeping the branchial fringes separate, at the same time that evaporation is checked by a humid atmosphere around. The respiration of some of the iuferior aquatic tribes, such as Crustacea, Mollusca, and Aunclida, has been examined with similar results. According to the researches of Humboldt and Gay Lussac, the air contained in water is richer in oxygen than that of the atmosphere; the proportion being 32 per cent. in the former, and but 21 in the latter.

424. The respiration of Insects has recently been made the subject of accurate research by Mr. Newport; aud the results which he has obtained correspond in a remarkable manuer with those of Dr. Edwards's experiments on Vertebrated animals under different conditions. In those tribes which undergo a complete metamorphosis, the proportion of air consumed by the *larva* is much smaller than that which the perfect insect requires, when their relative bulk is allowed for, and their condition is the same as to rest or activity. If a larva of the common butterfly, for instance, has arrived at its full size at the time of making the observation, it appears to respire in a given time more than the perfect insect; but the result is liable to this fallacy—that the former is at least two-thirds larger than the latter, and is almost always in a state of activity, whilst the latter is frequently in a state of quiescence. This fact is evidently analogous to one

ascertained by Dr. Edwards, that, in the higher animals, a greater quantity of oxygen is required in the adult state in proportion to the size of the respiratory apparatus, than in the infant condition. Again, many larvæ can support a degree of privation of oxygen which would be fatal to the perfect insect; thus, there are some which inhabit the bodies of other insects, or are buried deeply in the soil, or seek their subsistence in noxious and unaerated places, all of which situations would be soon destructive to life in an advanced condition. This, too, finds its parallel in the history of the Vertebrated classes: for Dr. Edwards found that puppies soon after birth will recover after submersion in water for 54 minutes, thus bearing the privation of oxygen much better than the adult animal. The amount of respiration in the perfect Insect depends chiefly upon its state of activity or excitement. When its movements are rapid and forcible, the aeration of the tissues must be performed to a greater extent than when it is at rest; and the difference is manifested, as well by the respiratory motions, as by the amount of oxygen consumed. Thus, the number of respirations in an Humble Bee (Bombus terrestris), while in a state of excitement soon after its capture, was from 110 to 120 in a minute; after the lapse of an hour they had sunk to 58, and subsequently to 46. Moreover a specimen of the same insect, confined in a limited quantity of air, produced in one hour after its capture, whilst still in a state of great activity, about $\frac{1}{3}$ of a cubic inch of carbonic acid; and during the whole twenty-four hours of the succeeding day, the animal evolved a quantity absolutely less. The amount of respiration in the pupa state is much less than in any other condition of the insect, which will readily be understood when its complete inactivity is remembered; the state of the animal at that time may be considered (as far as its respiration is concerned at least) in the same light as the hybernation of warm-blooded Vertebrata (§ 156).

425. In Insects, as in other animals, the activity of respiration is increased with elevation of the temperature of the surrounding medium. This has been shown in a very striking degree with regard to the Amphibia, by the researches of Dr. Edwards. It has been already mentioned that the cutaneous respiration of frogs is sufficient for the temporary support of life; and this holds good, not only when they are inhabiting the air, but even when immersed in water, provided the temperature be low. The air in the latter case must have a very feeble vivifying effect, on account of the small proportion of it diffused through the fluid; but it suffices to maintain the life of the animal as long as the temperature is below 50°. If, however, a slight increase of heat takes place, pulmonary respiration is necessary, and the animal takes in air at the surface of the water. During the heat of summer, pulmonary respiration aided by cutaneous respiration in water is not sufficient to counteract the effect of the high temperature; and cutaneous respiration in air becomes so necessary, that frogs confined to the water at this time almost certainly die. The

influence of temperature is seen also on the existence of fishes in limited quantities of water; and the degree of heat which obliges frogs to increase their respiration by quitting the water entirely, causes fishes to take in air from the surface, as may be frequently witnessed during the summer, especially in small collections of water. They sometimes quit their element almost entirely for a time, that the skin and branchiæ may be exposed to the vivifying action of the air.

426. It has been mentioned that during the development of the ovum, like that of the seed, the process of respiration is actively carried on. It is performed through the membranous tegument of the egg, or the porous covering of calcareous matter which in some tribes it possesses. If an egg be varnished over, so as to render it impermeable to gases, or be placed in irrespirable media, the development of the embryo is checked, though it may be renewed if the privation of oxygen has not been of too long continuance. As the watery portion of the albumen evaporates and the remainder is taken into the system of the fœtus, the quantity of the air originally existing in the egg becomes much increased; previously to incubation it contains as much as 25 or 27 per cent. of oxygen, but subsequently about 6 per cent. appears to have been converted into carbonic acid. In many cases this aeration is performed under peculiar circumstances, and special provision is accordingly made for it (§ 538).

CHAPTER X.

EXHALATION OF AQUEOUS VAPOUR.

General Considerations.

427. As all the alimentary materials taken into living bodies for the nutrition of their solid tissues are in a fluid form, being either dissolved in or mixed with water, it is evident that a large quantity of that liquid must be superfluous, and that means must be provided for carrying it out of the system. This is partly accomplished, in animals more especially, by its combination with various other ingredients,—which have either been introduced in greater quantity than the processes of nutrition require, or have already served their purpose in the vital economy,—into the fluid excretions, for the elaboration and deportation of which various structural contrivances are adapted. But besides the means thus afforded for the diminution of the superfluous fluid of the system, we find that the external surface has this special function imposed upon it, and that the disengagement of nearly pure aqueous vapour, though partly the effect of

simple evaporation, is principally dependent upon a true process of secretion, by which it is liberated from the circulating fluid. This is most evident in plants, where the quantity of fluid absorbed bears a much larger proportion to the amount of the solid matter contained in it than in animals; and where, from the little opportunity which there is for the introduction of superfluous nutriment, and the comparatively slight tendency to decomposition in the solid structures, the necessity for a constant excretion of other ingredients unfit to be retained is much less.

Exhalation in Plants.

428. The soft and succulent tissues of Vegetables, if freely exposed to the atmosphere, would soon lose so much of their fluid as to be incapable of performing their functions; and in all plants, therefore, which are subject to its influence, we find a provision for restraining such injurious effects. In the ALGÆ, however, and other tribes constantly immersed in water, or in a very moist atmosphere, no such loss can take place in their natural condition, and no means are required to prevent it. The outer layer of cells composing their integument differs but little from those which it holds together, except in density; and it is accordingly found that such plants, when exposed to a dry air, speedily desiccate. All plants whose natural residence is the air, however, are covered with a membrane of peculiar character, which is termed the *cuticle*. This is composed of cellular tissue, the vesicles of which are arranged with great regularity, and in close contact with each other; but they differ from those of the paremchyma beneath, in being colourless or nearly so, and in containing air instead of fluid. The form of these vesicles is different in almost every tribe of plants; thus in the cuticle of the Iris (Fig. 72) they have straight walls and regular angles, whilst in that of the Apple (Fig. 73) their boundaries have a sinuous character. In most European plants, the cuticle contains but a single row of these cellules, which are moreover thin-sided; whilst in the generality of tropical species, there exist two, three, or even four layers of thick-sided cells, as in the Oleander (Fig. 70), the cuticle of which, when separated, has an almost leathery toughness. In this plant the cuticle is also covered with hairs, which may not only serve as an additional resistance to exhalation, but probably assist in absorption also (§ 254); and these hairs not only clothe the surface, but line the cavities which replace the stomata on the lower side of the leaf (Fig. 70, *e*, *e*). This difference in conformation is obviously adapted to the respective conditions of growth; since the cuticle of a plant indigenous to temperate climates would not afford a sufficient protection to the interior structure, against the rays of a tropical sun; whilst the diminished heat of this country would scarcely overcome the resistance afforded by the dense and non-conducting tegument of a species formed to exist in warmer latitudes. From the researches of Ad.

Brongniart it appears that, externally to this membrane, there exists a very delicate transparent pellicle, without any decided traces of organisation, though occasionally somewhat granular in appearance, and marked by lines which seem to be the impressions of the junction of the cells with which it was in contact. He thinks that he has traced this membrane where the real cuticle does not exist, as on the apex of the stigma, and the general surface of submerged vascular plants. It is perforated by apertures leading to the *stomata*, where they exist in the cuticle; and would seem to bear a very close analogy to the epidermis of animals (§ 39).

429. In the cuticle of most plants which possess this structure distinctly formed, there exist minute openings termed *stomata*, which are bordered by cellules of a peculiar form, distinct from those of the cuticle, and more resembling in character those of the tissue beneath. These boundary cells are usually kidney-shaped (Figs. 72, 73, *a*, *a*), and the opening between them oval, as at *c;* but, by an alteration in their form, the opening may be contracted or completely closed. They are sometimes more numerous, however, and the opening angular; and in the curious *Marchantia polymorpha*, their structure is extremely complicated. The openings in the cuticle of this plant are surrounded by five or six rings placed one below the other, so as to form a kind of funnel or chimney, each ring being composed of four or five cellules (Fig. 52). The lowest of these rings appears to regulate the aperture, by the contraction or expansion of the cells which compose it. Wherever stomata exist in the cuticle, they are always found to open into cavities in the tissue beneath, which are thus brought into immediate relation with the external air (Fig. 71, *c*). In the Marchantia these chambers are very large and surrounded by regular walls; whilst in the leaves of higher plants they exist simply as intercellular spaces, left by the deficiency of the tissue. Stomata do not exist where there is no regular cuticle; and they are consequently not found upon the lower cellular plants, and but very rarely on Mosses. They are not formed upon the cuticle of any plants growing in darkness, nor upon the roots nor the ribs of leaves; but they exist in general on all foliaceous expansions, and on herbaceous stems, especially on those of which the surface performs the functions of leaves, as in the *Cacti*. They are most abundant on the under surface of leaves, except when these float on water, and then they are found on the upper side alone; but they exist equally on both surfaces of erect leaves, as in the Lily tribe and Grasses. As a general fact they are least abundant on succulent plants whose moisture is to be retained in the system; and they are frequently so imperfectly formed as not to have any tendency to open, especially on the leaves of those adapted to exist in hot and dry situations. In the Oleander, which has to bear the parched atmosphere of a Barbary summer, the stomata of the lower surface are replaced by cavities lined with hairs,

the probable function of which has just been explained. In all instances where stomata exist, the tissue beneath is very loosely arranged, and contains many intercellular spaces; in the greater number of leaves therefore, the most closely-packed cells will be found on the upper side (Fig. 69, *b*, *b*); and it is from this that the darker colour of the superior surface is principally derived. If a leaf be placed in water, and the pressure of the air above be taken off, a number of minute globules will be seen to escape from these cavities, and to stud its exterior with brilliant points.

430. The loss of fluid from the surface of plants may take place, as has been said, by simple *evaporation*, or by exhalation. The quantity of the former will be regulated by the degree of moisture in the tissue exposed to the atmosphere, and by the compactness of its arrangement. Thus, although the simpler terrestrial cellular plants have no true cuticle distinct from the subjacent tissue, their external layer of cells is generally of so dense a consistence as to be almost impervious to water; so that their moisture is very slowly evaporated. The process is one quite independent of vitality, and is, indeed, the means by which dead plants are dried up, and by which the gradual loss of weight takes place from fruits, tubers, &c., that undergo no other alteration. It will, therefore, be influenced by those obvious external causes under the control of which the process is universally performed,—namely, variations in temperature and in the humidity of the surrounding medium. *Exhalation*, on the other hand, is a change which only continues during the life of the plant, and appears to be closely connected with the performance of its other vital functions. If a piece of glass be held near the upper surface of a leaf in full growth in a hot-house, it is scarcely dimmed after some time; but if in proximity with the lower surface of the same leaf, it is speedily bedewed with moisture, which accumulates in a short time so as to form drops. This rapid transpiration of fluid appears to take place through the stomata, as it is now satisfactorily proved that it bears a strict relation (other things being equal) with the number of stomata in the plant, or on the particular part of it made the subject of examination.

431. Various experiments have been made at different times, with the view of ascertaining the quantity of water thus transpired from different plants, and the circumstances most favorable to the process. With regard to *quantity*, the results obtained by Dr. Woodward* are among the most worthy of attention, although probably the earliest on record. Four plants of spearmint were placed with their roots in water, and in a situation fully accessible to light, during 56 days (from June 2nd to July 28th); and the following table exhibits the quantity of water which each plant absorbed, (proper allowance being made for the evaporation from the surface of the fluid), and its increase in weight at the end of the experiment.

* Philos. Trans. 1699.

The *difference* must of course be the quantity exhaled, and would scarcely express the whole amount of it, as part of the increase in weight would be due to the fixation of carbon from the atmosphere.

	Original Weight.	Gain.	Water expended.	Difference.
No. 1.	127 grs.	128 grs.	14,190 grs.	14,062 grs.
No. 2.	110 grs.	139 grs.	13,140 grs.	13,001 grs.
No. 3.	74 grs.	168 grs.	10,731 grs.	10,563 grs.
No. 4.	92 grs.	284 grs.	14,950 grs.	14,666 grs.

Nos. 3 and 4 were immersed in water with a little earth at the bottom.

These experiments give satisfactory evidence of the very large proportion of the absorbed fluid which is given out again by transpiration; and, joined with others by the same individual, they show that the activity of this function is much greater in summer than in the autumn. A valuable series of experiments, communicated by Guettard to the Academie Royale in 1740, confirms this conclusion. He stated that transpiration is so much less active during the winter than at other parts of the year, even in evergreens, that a laurel parts with as much fluid in two days in summer, as during two months in winter. He also maintained that transpiration goes on much more rapidly under the influence of light and a moderate degree of heat, than at a high temperature and without light. One of his most striking experiments is that upon the *Cornus Mascula* (cornel), the young shoots of which he found to lose *twice their own weight* of water daily. The experiments related by Hales in his essays on Vegetable Statics will ever remain, like those which he performed on the animal circulation, a monument of his skill and perseverance. The results which he obtained from the accurate observation of a specimen of *Helianthus annuus* (sunflower) during 15 days, are those most frequently quoted by succeeding authors; but there are many others scarcely less interesting. This plant was $3\frac{1}{2}$ feet high, weighed 3 lbs., and the surface of its leaves was estimated at 5616 square inches. The mean perspiration during the whole period was found to be 20 oz. per day; but on one warm dry day it was as much as 30 oz. During a dry warm night it lost 3 oz.; when the dew was sensible though slight, it neither lost nor gained; and by heavy rain or dew it gained 2 or 3 oz. The following table shows the results of similar experiments on other plants.

Subject.	Surface.	Mean Transpiration.	Greatest Transpiration.	Depth.
Cabbage	2736 sq. in.	19 oz.	25 oz.	$\frac{1}{80}$
Vine	1820 sq. in.	$5\frac{1}{2}$ oz.	$6\frac{1}{2}$ oz.	$\frac{1}{191}$
Apple	1589 sq. in.	9 oz.	15 oz.	$\frac{1}{102}$
Lemon	2557 sq. in.	6 oz.	8 oz.	$\frac{1}{248}$
Plantain	2024 sq. in.	5 oz.	$11\frac{1}{2}$ oz.	$\frac{1}{112}$

The last column shows the mean quantity of water transpired from equal areas in the different plants (its depth being stated in parts of an inch)

for the sake of ready comparison. That of the sun-flower would be $\frac{1}{105}$ and is shown, therefore, to be less than half that of the Cabbage. The Lemon may be remarked to have exhaled far less than any of the others; and the same observation seems true with regard to evergreens in general. The mean transpiration from the skin of the human body in health, with the exhalation from the lungs, may be stated at about 45 to 50 oz. in twenty-four hours. The external surface may average about 2160 sq. in.; but the surface of the mucous membrane of the lungs cannot be estimated. An experiment performed by Bishop Watson will assist in giving an idea of the extraordinary amount of change performed by this function in plants. He placed an inverted glass vessel, of the capacity of 20 cubic inches, on grass which had been cut during a very intense heat of the sun, and after many weeks had passed without rain; in two minutes it was filled with vapour, which trickled in drops down its sides. He collected these on a piece of muslin which he carefully weighed; and, repeating the experiment for several days between twelve and three o'clock, he estimated as the result of these enquiries, that an acre of grass land transpires in 24 hours not less than 6400 quarts of water. This is probably, however, an exaggerated statement; as the amount transpired during the period of the day in which the experiment was tried, is far greater than at any other.

432. All experiments point to the conclusion that *light* is the chief stimulus to exhalation. Thus, it was shown by Senebier that if plants, in which the process is being vigorously performed, are carried into a darkened room, the exhalation is immediately stopped; and that the absorption by the roots is checked almost as completely as if the plant had been stripped of its leaves. Again, from the experiments of Dr. Daubeny, it appears that exhalation is stimulated by the coloured rays of the solar spectrum in proportion to their *illuminating* not to their *heating* power, these two being separated by the prism. Dr. D. further states that exhalation is not promoted by the most intense degree of artificial light, in which he contradicts the opinion expressed by Decandolle.* Still, it must be acknowledged that heat also, especially when combined with dryness of the atmosphere, has a greater effect upon the loss of fluid than light only. Thus, it is well known that plants perspire in a sitting-room, the air of which is constantly dry but which is imperfectly illuminated, so much more than in the open air exposed to the direct rays of the sun, that it is impossible to keep many kinds alive in such a situation. It would not seem improbable, then, that the effect of light is confined to the opening of the stomata, which it is known to perform; and that the large quantity of fluid discharged from them may be due to the effect of simple evaporation from the extensive surface of succulent and delicate tissue which is thus brought into relation with the air, and to the constant supply of fluid from within by which it is maintained in a moist

* Philosophical Magazine, May, 1836.

condition. Electricity appears to possess, like light, a direct stimulating power over the exhaling organs of plants. It has been generally admitted that the electric state of the atmosphere has a considerable influence in hastening the growth of many vegetables (§ 186). Decandolle states that experiments with artificial electricity satisfactorily prove, that plants submitted to its influence exhale more by a fourth or a third than similar ones not electrified; and in some cases, especially when sparks are drawn, the water has been seen to accumulate in drops.

433. If plants are exposed to a light of too great intensity, especially if they are not at the same time well supplied with water, their tissue becomes dried up by the increased exhalation which then takes place, and which is not sufficiently counterbalanced by absorption, so that their vegetation is materially checked;—a fact of which we see abundant evidence in dry sandy soils and exposed situations. If, on the contrary, the leaves are shaded, and the roots take up much moisture, the growth of the plant is active and luxuriant, but its tissue is soft;—an effect partly owing to the retention of fluid, and partly to the diminution of the quantity of carbon fixed from the atmosphere. If a plant be kept for some time in total darkness so that it becomes *etiolated* (§ 373), its texture is soft and succulent, and its tissue is distended with the moisture it has absorbed and with which it cannot part; and if this state be allowed to continue too long, the leaves disarticulate and drop off, and the plant dies of dropsy. Succulent plants naturally require most light to secure for them a regular discharge of moisture; hence Mr. Knight enforces the propriety of exposing as many leaves as possible in the Melon frame to the action of the sun's rays. There are some of this character which possess so few stomata, that they may be preserved out of the ground for many days and even weeks, without perishing from want of moisture; and it sometimes happens that *Sedums* and other such plants push considerable shoots when placed under pressure whilst being prepared for the Herbarium. The quantity of fluid lost by Transpiration, though ultimately dependent upon the degree of moisture supplied to the roots, does not appear to be increased by the propellent force of the sap; and this, observes the sagacious Hales, "holds true in animals, for the perspiration in them is not always greatest in the greatest force of the blood; but then often least of all, as in fevers." The water exhaled is very nearly pure, so that what is furnished by different species varies but little in taste or odour. Duhamel remarked, however, that fluid thus obtained sooner becomes foul than ordinary water. Senebier analysed the liquid which he had collected by the exhalation of a vine at the commencement of the summer, and found that 40 oz. contained scarcely 2 grains of solid matter; and in a similar experiment on fluid collected at the end of the summer, 105 oz. gave but little more than 2 grains, or about $\frac{1}{25000}$ part of solid matter.

Exhalation in Animals.

434. The loss of fluid which is constantly taking place from the surface of all animals inhabiting the air, or at least from some part of it, appears due, like the exhalation of plants, partly to its physical, and partly to its vital conditions. There can be no doubt that from all soft moist surfaces *evaporation* will take place in a warm and dry atmosphere; and the quantity of fluid lost in this manner will be in strict relation with the temperature of the surrounding medium, and the rapidity with which it is supplied to the evaporating surface. This process will of course be impeded by a humid state of the atmosphere, and entirely checked by contact of water—whether warm or cold—with the part which previously effected it. But there is another process by which fluid is exhaled from the surface, and which possesses the character of a true *excretion;* this is effected by the separation from the blood of a watery fluid, usually containing a small quantity of saline and animal matter in solution, through the medium of a set of minute glands imbedded in the substance of the cutis or true skin. Each of these little bodies consists of a convoluted tube, in the neighbourhood of which the blood-vessels ramify minutely; this tube is continued to the surface of the skin as an excretory duct (Fig. 153), traversing the remaining thickness of the cutis and epidermis in a spiral manner, and opening by a very minute pore on the exterior of the latter, passing through it so obliquely that a kind of valve is formed by the membrane over its orifice. When the transudation of the sweat or sensible perspiration is observed with a glass, as it occurs on the palms of the hands or the tips of the fingers, the first drop from each pore will be seen to be preceded by an elevation of this little valve. These ducts are visible in the form of delicate fibres passing from the cutis to the epidermis, when the latter is torn off; their diameter is stated by Dr. Madden* to be $\frac{1}{450}$ of an inch, the canal occupying about one-third of their breadth.† It has not yet been ascertained how low in the animal scale these organs exist; the only species in which they have been hitherto detected being included in the class MAMMALIA.

435. No investigations have yet been made upon the function of exhalation in the aquatic INVERTEBRATA, with the view of determining to what extent it is one of the regular processes of their economy. Although simple evaporation will of course be prevented by the contact

* Essay on Cutaneous Absorption, p. 19.

† Another apparatus has been described by Dr. Wallace as being part of the exhalent system,—namely, a set of "epidermoid glands" situated between the inner and outer layer of epidermis, which he states to exist at the points from which the drops of sweat are seen to issue. The author is disposed to agree with Dr. Madden (Op. Cit. p. 24), however, in believing that Dr. W. has been deceived on this point, and that the supposed glands are nothing more than the shrunk and contracted ducts of the true secreting organs of the perspiration.

of their surfaces with water, there is no reason to suppose that a secretion of fluid may not take place from them, as from the skin of the higher animals under similar circumstances. When exposed to the air, all those which are formed of soft tissue, unprotected by a hard envelope, are rapidly desiccated, and usually perish; but, that the whole of the fluids of the body may thus be lost by evaporation, and vitality still remain, is shown by the statement formerly made respecting the ROTIFERA (§ 93). It is evident that such animals are, when exposed to the atmosphere, in the same condition with the Algæ among plants, which lose weight so rapidly owing to the softness of their tissues and the want of a cuticle. Even amongst those which are provided with a hard envelope, there is always a peculiar tendency to evaporation from some parts of the surface; thus, a very rapid exhalation of fluid takes place from the gills of the CRUSTACEA, which would speedily offer a fatal impediment to the performance of their functions, if a special provision were not made for preserving their membrane in a humid condition (§ 400). From the experiments of Dr. Edwards on FISHES, it appears that the loss of fluid by evaporation from the general surface of the body and from the gills, when the animal is exposed to the air, is so great as to be one of the chief causes of its death. Sometimes the impediment to respiration, which is produced by desiccation of the gills, is the immediate cause of death; but where this is prevented, and the action of these organs continues during life, the surface parts with so much fluid by evaporation that the body becomes stiff and dry, and previously to death loses from $\frac{1}{14}$ to $\frac{1}{15}$ part of its weight. It has been shown that if the lower part only of the body be immersed in water, no absolute diminution in weight of the whole takes place, and life is prolonged, although death seems at last to result from the unfavourable influence of dry air upon the branchial apparatus; but if, on the other hand, the head and gills be immersed and the trunk suspended in air, life may be almost indefinitely prolonged, although the drying of the surface of the part of the trunk exposed to the air was as marked as in the case where these animals were entirely exposed to the atmosphere, and where they died after a considerable diminution in weight.

436. It is among terrestrial animals that the process of exhalation assumes a higher rank amongst the vital functions; and, even in the lowest orders, we find it exercising a very important influence on the condition of the system. Thus, in INSECTS, it has been ascertained by Mr. Newport, that the transpiration of fluid takes place to a considerable extent; and this not only in the species which have a soft external tegument, but among those which have the body encased in a dense horny envelope, such as the beetle tribe. It is of course difficult to ascertain what proportion of the loss of fluid takes place in each case from the external surface, and from the prolongation of it that lines the air

passages, which in this class are so extensive and minutely ramified; probably it is from the respiratory membrane, as in the Crustacea, that the principal liberation of it occurs. The peculiar object of the disengagement of fluid in the form of vapour, is evidently the reduction of the temperature of the surface from which it is set free. Animals which inhabit the water have no need of any special provision for keeping down the temperature of their bodies within a certain limit; since the rapidly-conducting power of the medium is sufficient to reduce any superfluous amount of caloric which may be generated. The tenants of the deep, therefore, have very little power of maintaining a temperature above it, unless they are provided, like the whale tribe, with a layer of non-conducting fat, or, like diving birds, with a downy covering possessed of a similar property (§ 491). Moreover, the vicissitudes of temperature in large collections of water are never great, so that there is no demand from this source for a means of regulating the temperature of the individual inhabitants. But an animal living upon the surface of the earth, exposed to constant and extensive atmospheric changes, and deprived of the power of rapidly parting with its heat, when superfluous, by mere contact with a conducting medium, has need of some special means not only of generating caloric, but also of getting quit of it. The former will be hereafter described in detail (CHAP. XII.); the latter is simply effected by the secretion of sweat from the surface, which, being poured out of the perspiratory ducts in a fluid form, and carried off as a vapour by the atmosphere, necessarily renders latent a large quantity of caloric, and thus diminishes the sensible heat of the exhaling body. The observations of Mr. Newport on Insects show that they have the power of thus reducing their temperature when excessively raised by a continuance of rapid movements, or when the heat of the surrounding medium is too great (§ 490).

437. It is among the *Batrachia*, however, that the exhalation of fluid from the surface is carried on to the most evident degree, and seems to answer the most important purpose in the economy; and it is here, therefore, that its conditions may be most advantageously studied. The experiments of Dr. Edwards on this subject are extremely interesting, and a brief account of them will now be given. He found that when a frog was placed in a dry calm atmosphere, the loss of weight during different succeeding hours varied considerably, but with a marked tendency to progressive diminution: that is to say, the more fluid the animal had lost, the less actively did exhalation go on. The actual quantity lost was influenced by various external agents, such as the rest or movement of the air, its temperature, and degree of humidity. Thus, frogs, hung in the draft of an open window, lost double, triple, or quadruple the amount exhaled by others placed at a closed window in the same room. The influence of the humidity of the air was tested by

placing animals of the same kind in a glass vessel inverted over water; and it was ascertained that exhalation, if not then entirely prevented, was reduced to its minimum. On the other hand, when the dryness of the air was maintained by quicklime during the progress of the experiment, the diminution of weight was found to be increased, the perspiration being from five to ten times greater in dry air than in extreme humidity, according to the duration of the experiment. The influence of temperature is shown principally in increasing the transudation or secretion from the skin; since the amount of fluid lost in a heated atmosphere differs but little whether the medium be humid or dry, and increases in much more rapid proportion than mere evaporation would do. When frogs were placed in an atmosphere saturated with humidity, by which mere evaporation would be almost or entirely suppressed, the loss by transudation between 32° and 50° was very slight, as also between 50° and 68°; but between 68° and 104° it was so great, that at the last-named degree its amount was 55 times that at 32°. The secretion is not even altogether suppressed by immersion in water. When frogs are exhausted by excessive transpiration and are placed in water, they speedily repair the loss by absorption from the surrounding fluid (§ 279); and the quantity thus gained sometimes amounts to *one-third* of their entire weight.

438. From his experiments on the higher animals, Dr. Edwards obtained results of a similar kind; but the influence of changes in external conditions was not quite so marked. The distinction between the simple evaporation which takes place in obedience to physical laws, and the transudation which is the result of a secreting process, must be kept in view in order to account for their effects under different circumstances. It might, at first sight, appear to correspond with that between *insensible* or vaporous, and *sensible* or liquid transpiration; but this is not altogether true, since the *secretion* of the skin, if not very abundant, may pass off in the same form with the vapour which arises from its surface. The degree of *evaporation* from the skin of warm-blooded Vertebrata is modified, as in the Batrachia and other cold-blooded animals, simply by the temperature, degree of humidity, movement, or pressure of the surrounding medium. Wholly to suppress it, the air must not only be of extreme humidity, but also at a temperature not inferior to that of the animal; since, if the air be colder, it will be warmed by contact with the body, and thus be capable of holding an additional quantity of aqueous vapour in solution. Although cold, therefore, diminishes or even altogether suppresses transudation, evaporation will continue to a certain extent. In man, as in the Batrachia, it seems probable that heat alone stimulates the function of *secretion* from the skin; so that at moderate temperatures and in ordinary states of the atmosphere the quantity transuded is not more than one-sixth of that which is evaporated: whilst at an elevated tempe-

rature, especially if the air be already humid, the amount of secretion will much surpass that lost by evaporation; but if the air be dry and sufficiently agitated, evaporation may increase nearly in the same ratio.*

439. The amount of fluid exhaled in the form of vapour from the lungs appears to be usually somewhat more than that transpired from the surface. There is no reason to believe that it is liberated in any other way than by *evaporation*, under the peculiarly favourable circumstances afforded by the delicacy and permeability of the respiratory membrane, its constant supply of fluid blood, and the frequent renewal of the air in contact with it. It is obvious that changes in the external conditions will have much less influence upon *its* amount than upon the quantity evaporated from the skin; since the temperature of the air in the pulmonary cells will be nearly uniform under all circumstances (in the healthy state at least), and its movements are uninfluenced by the variations of the atmosphere. If, however, the external air were saturated with moisture, and of the same temperature with the body (so as to be unable to acquire by its heat an increased capacity for vapour), it is obvious that the evaporation from the lungs, as well as that from the skin, will be entirely checked.

440. From the experiments of Lavoisier and Seguin it appears, that the maximum quantity of fluid exhaled from the cutaneous and pulmonary surfaces in man is 5 ℔., the minimum being $1\frac{3}{4}$℔.; and that the mean quantity exhaled per minute is 18 grs., of which 11 pass off by the skin and 7 by the lungs. There is much difficulty in attaining correct information on this subject, however, owing to our ignorance of the amount absorbed from the atmosphere; and that, under favourable circumstances, the quantity of fluid exhaled from the skin may be much greater in a short time than these results would lead us to believe, appears from the late observations of Dr. S. Smith.† These were made upon labourers at the Phœnix Gas Works, who are employed twice a day in drawing and charging the retorts and in making up the fires, which usually occupies about an hour; the labour is performed in the open air, but is attended with much exposure to heat. On a foggy and calm day at the end of

* It has been stated as the result of the experiments of MM. Delaroche and Berger, that not only the heat but the humidity of the atmosphere stimulates transudation; since they uniformly found that air excessively hot, and charged with extreme humidity, excited a more abundant perspiration than dry air at a higher temperature; but this result may be due to the accumulation of fluid on the surface, in the former condition, which would have been rapidly dissolved by the air in the latter. It is sufficiently evident, however, that a humid state of the atmosphere does not check the *secretion* of fluid in the skin; and the same may be said of the contact of warm fluid. There is good reason to believe that the loss of weight which frequently takes place in the warm bath, though partly to be accounted for by the continuance of pulmonary exhalation, also results in part from cutaneous secretion,—the diminution having been, in one of Dr. S. Smith's experiments, as much as 8 oz. in half an hour, although the body was previously in a state of exhaustion from labour in a heated atmosphere.

† Philosophy of Health, vol. ii., 322, &c.

November, when the temperature of the external air was 39°, and the men continued at their work for an hour and a quarter, the greatest loss observed was 2 lb. 15 oz.; and the average of eight men was 2 lb. 1 oz. On a bright clear day in the middle of the same month, when the temperature of the air was 60° with much wind, the greatest loss was 4 lb. 3 oz.; and the average was 3 lb. 6 oz. And on a very bright and clear day in June, when the temperature of the external air was 60° without much wind, the greatest loss (occurring in a man who had worked in a very hot place) was 5 lb. 2 oz.; and the average during the hour was 2lb. 8 oz. If, as seems probable, a large proportion of the fluid thus rapidly exhaled would be speedily replaced by absorption from the atmosphere, it is obvious that no calculation of the total daily amount can be accurate which is based only on the relative quantities of the ingesta and egesta.

CHAPTER XI.

SECRETION.

General Considerations.

441. Although the function of Secretion might not, at first sight, appear so universal in organised beings as those already described, there can be little doubt that it is no less essential to their existence, since there is reason to believe that it takes place under some form in every living structure. The term *Secretion* implies a *separation* of some portion of the constituents of the organism; and although it has been usually employed to designate the elimination from the circulating *fluid* of products existing under the *same* form, it is much better to extend its application to the evolution of aqueous vapour, and of carbonic acid in a gaseous state (already described under the heads of Exhalation and Respiration), since these take place under precisely the same conditions and must be regarded as a part of the general function. The necessity for this constant separation of a portion of the elements of the structure would seem to arise in part from the constant tendency to decomposition, which is common to the solid and fluid portions of the organism, and which, if unchecked by the deportation of the particles thus liberated (§ 232), would speedily derange the train of vital functions. By the process of interstitial absorption, these particles are taken into the current of the circulation, and are thus conveyed to the organs which are to separate them. It is not difficult to understand that, in proportion to the simplicity of the nutrient

processes, and the homogenous character of the structure, will be the simplicity in the character of this function; but that it will increase in complexity and importance as the number of different parts is augmented, and they become mutually dependent upon one another. A general survey of the processes of secretion as performed in the Vegetable and Animal kingdoms will also show that their activity bears a close relation with the tendency to decomposition in the constituents of the organism. Thus, in Plants, a large proportion of the fabric usually possesses a character so permanent that it may remain almost unchanged for an indefinite time; and those parts which are of softer texture and more actively employed in the vital processes, and which are therefore more prone to decay, are not constantly renovated by interstitial absorption and deposition, but are periodically thrown off and renewed. There is no occasion, therefore, in them for great activity in the excretory functions; and we find that little is regularly throwu off from the system besides carbonic acid and aqueous vapour. In Animals, on the other hand, all the softer tissues possess a strong tendency to decomposition; and the constant maintenance of their normal condition, which is required for the performance of their functions, is provided for by the continual replacement of their constituents, and the activity with which the effete particles are carried out of the system.

442. It might be expected, theu, that the retention in the circulating fluid of the matters destined to be excreted, would have an injurious effect on the system; and this is well known to be the case. If the function of Respiration be checked, either in Plants or Animals, death speedily results, the nutritious fluid losing its vital properties, and acquiring others absolutely injurious; if Exhalation be impeded, the tissues become gorged with fluid, and a general injury to the health of the system soon becomes apparent; and any obstruction to the more constant aud therefore more important special secretions speedily manifests itself in the disease or death of the fabric. But the necessity for excretion does not arise only from the sources just mentioned; for it cannot be deemed improbable that the changes which the crude aliment undergoes, from the time of its first reception into the absorbent vessels to that of its conversion into organised tissues, involves the liberation of many products, of which the elements are superfluous and therefore injurious to the system if retained in it. An example of this kind has been already adduced (§ 366). Moreover, the elaboration of secretions is evidently required, not only to free the circulating fluid from some ingredient, the predominance of which would be injurious to its properties, but to carry on various processes in the vital economy. Thus, the secretion of saliva, that of gastric juice, bile, pancreatic fluid, &c., contribute to the performance of the function of digestion, by their influence upou the aliment which is to be reduced to a state fit for absorption. In like manner, the secretion of tears is adapted to lubricate and cleanse from impurity the surface of the eye; whilst the

poison of the serpent's fang, formed by one of the salivary glands,—the ink of the Sepia, a secretion of a urinary character (§ 274),—the glutinous material which forms the web of the Spider,—and many other fluids, serve a purpose even more directly important in the economy of the animals to which they belong, supplying them with the means of securing their prey, or of escaping from their enemies. Other secretions, again, are connected with the reproductive functions. Of all these it may be remarked that, although they are obviously destined for a special purpose when removed from the blood, it it is by no means improbable that their separation from the circulating fluid has, like that of the regular excretions, an important influence on the maintenance of its healthy character. Further, we may observe in the *form* which the regular excretions assume, an adaptation to particular purposes in the economy. Thus, the separation of bile from the blood appears equally necessary for the liberation of part of its superfluous carbon, and for the process of chymification. The excretion of carbon in a gaseous form, by Respiration, on the other hand, serves to maintain the heat of the body, and to facilitate the introduction of oxygen into the system, according to the laws of the diffusion of gases already stated (§ 371). And the constant Exhalation of aqueous vapour from the surface, with the occasional formation of sensible perspiration, serves not only to prevent the injurious accumulation of the absorbed fluid, but to keep the temperature down to its proper standard.

443. The function of secretion is one whose nature can be but little elucidated by anything at present known of the processes of Organic Chemistry. It may be stated as a general fact that the peculiar products contained in the secretions exist in the circulating fluid, if not altogether ready formed, at least in a state nearly allied to that which they afterwards present. The grounds of this statement will be hereafter given. The process of Secretion is, therefore, truly one of separation; but the difficulty is to understand why each gland should secrete a fluid peculiar to itself, —how this excretion is so much influenced in Animals (as it unquestionably is) by the nervous system,—and how, in particular cases, secreting surfaces should separate fluids of a different character from their own, and to which other organs are usually appropriated (§ 471). The phenomena of Endosmose (§ 244, 5), and those of electrolytic action (§ 165) seem to have some connection with the process; but the nature of that connection is very obscure. The analogy of Respiration, however,—in which the liberation of carbonic acid has been shown to be a change in itself obedient to physical laws, although dependent upon vital action for its maintenance (§ 370-2),—seems to indicate that an explanation of a similar character may hereafter be applied to other departments of the function. It may be surmised without improbability that the *selecting* power of the secreting membranes may be due, like that of the absorbent vessels of plants and animals, to the peculiar character of their organisation (§ 275); and that

any change in the nutritive processes may thus modify it. Some observations will be hereafter mentioned (§ 501) which would seem to indicate that the electric state of the different glands has some influence on the nature of their secretions, as on the physical phenomena of Endosmose.

Secretion in Plants.

444. There is no subject in Vegetable Physiology more obscure than the object of the innumerable products of vital chemistry, some of which abound in every tribe of plants. The greater proportion of the compounds which are formed in the elaboration of the sap, and which are afterwards separated from the mass of the circulating fluid, are not carried out of the system (like the excrementitial secretions of animals), but are stored up within it in special receptacles, where they appear to undergo but little alteration, and not to be perceptibly connected with the nutrition of the fabric. It would seem probable, from what is at present known of the subject, that all those special secretions of Plants, of which one or more seem peculiar to almost every natural order, exist in the *latex* or nutritious fluid which has been formed by the action of light, air, &c., upon the crude sap brought to the leaves (§ 286); for although they are usually found to exist in greatest abundance in some particular portion of the fabric, especially the bark or fruit, the action by which they are deposited there would seem to be rather one that *separates* them from the general mass of the circulating fluid, than one of formation. Some doubts may exist with regard to the secretions for the elaboration of which we find special glandular organs destined; and it is very possible that in these some simple chemical changes may be effected by which their peculiar products may be eliminated from the elements already existing in the fluid under some different form. But so little attention has been bestowed upon this department of the subject, that we cannot do more than speculate upon it. It is unquestionable that, upon the changes effected in the leaves, the formation of the special secretions depends; and we can scarcely doubt that the principal agent concerned is *light*, since tropical plants never fully attain their natural fragrance, or their other peculiarities, when grown under the influence of artificial *heat* in temperate climates.

445. Upon the special secretions of Vegetables there is no occasion to dilate here at much length; since, little being known of them beyond their sensible properties, and their purposes in the vegetable economy being almost entirely unascertained, they fall much more within the province of the Chemist than that of the Physiologist. The various crytalline inorganic substances, which are found in different parts of the tissues of plants, were formerly supposed to be the direct products of the vegetative processes; more accurate investigations have proved, however, that they are all derived immediately from the soil, or introduced in some way by absorption with water. In a few instances, however, the matter which

enters the plant forms subsequent combinations with the undoubted products of vegetation; thus, lime is combined with oxalic acid, so as to form the *raphides* (delicate needle-like crystals) so abundant in the tissues of Rhubarb; but in general it is deposited unchanged in those parts where the process of exhalation is being carried on with the greatest rapidity. Hence these extraneous substances abound much more in the leaves than in other parts; and more in the bark than in the wood. Herbaceous plants, for the same reasons, furnish more ashes, in proportion to the weight of their solid contents, than trees. The pure vegetable secretions are all the result of the combination of the elements of water with carbon, to which nitrogen is added in some cases. Out of the large number of distinct principles which have been analysed by chemists, there are but very few in which oxygen, hydrogen, and carbon are not the components; the principal exceptions being the essential oils of turpentine and lemons, which are compounds of carbon and hydrogen alone. The means by which this immense variety is produced from elements so simple, is one of the most curious mysteries of Vital Chemistry; and it must be long before we are enabled to imitate its effects, or even to understand its method of operation. It is necessary to bear in mind that the processes which are employed for the separation and analysis of vegetable secretions frequently produce important alterations in their character. Thus, from the pulp of bitter almonds by compression alone a fixed oil is obtained; but, when distilled with water, a volatile oil, mixed or combined with hydrocyanic acid passes over, neither of which compounds pre-existed in the substance. The oil is a compound of a base (which has been termed *benzule*, and which consists of carbon, hydrogen, and oxygen,) with another equivalent of hydrogen, which it probably obtains from the water during distillation; and this base, though not obtainable in a separate form, may be transferred to other combinations. In like manner, the volatile oil of mustard, which is so irritating to the eyes and nostrils, appears not to pre-exist in the seed, but to be formed when water is added to its substance in a finely pulverised state.

446. The *milkiness* of the proper juices of many plants is caused by their holding in solution or suspension various products, besides those which conduce immediately to the nutrition of the system. When plants containing them are wounded, the milky fluids are forced out from both lips of the incision, showing that its effusion results from the contraction of the vessels which contain them; but this contractility is destroyed by an electric shock. Although differing in composition in almost every species, they may be classed under three general divisions. 1. Fluid in which *caoutchouc* is present. This is most common in tropical plants, especially those belonging to the families *Artocarpeæ* (Bread fruit-tribe), *Apocyneæ* (Oleander tribe), and *Euphorbiaceæ* (Spurge-tribe); and, from some of these, India rubber is usually obtained, though it exists in many

others also. 2. Narcotic milk, in which *opium* is an essential ingredient, and which is principally met with in the *Papaveraceæ* (Poppy tribe); the juices of the *Cichoraceæ* (Endive tribe), and of the *Campanulaceæ*, owe their sedative properties to a very analogous principle. 3. Milky juices which contain no trace of opium or caoutchouc, but hold in solution a large quantity of a principle analogous to animal fibrin. Of this kind are the milk of the *Papaw;* and that of the *Palo di Vaca* or Cow-tree of South America, described by Humboldt, which is used as food by the natives.

447. All the milky juices exist in the bark and leaves alone, and may be extracted by incisions made in their tissues. Though they are not usually destined to be excreted, there are some plants, such as the *Lactuca virosa* (wild Lettuce), in which the reservoirs of the proper juices are so irritable, especially at the time of flowering, that their contents are expelled by the slightest touch. Many plants naturally containing them may be used as food at a period antecedent to their formation, or by preventing it; thus the lettuce, cichory, and sea-kale are rendered fit for the table by growing them in diminished light, or by heaping earth around their young shoots, so as to etiolate them (§ 373); and the Languedoc peasants eat young poppies with impunity. These proper juices sometimes exist in the roots even in considerable abundance; and, as we shall hereafter see (§ 454), probably contribute to form the excretions which are thrown out from their surface.

448. The next class of special secretions to be considered includes those which are completely separated from the circulating system of the plant, and which appear to have no relation, except in one or two instances, with the functions of vegetation; they are sometimes found in a fluid, sometimes in a solid state, and seem generally to remain stored up in the part where they are formed; but occasionally they accumulate, and find their way downwards by the force of gravity and the natural permeability of the tissue, so as to become extensively distributed, although they have no regular circulating system. The structure of the parts specially adapted for the elaboration of these secretions has not been sufficiently investigated. They are occasionally formed by *glands*, which consist of little but cellular tissue in a state of peculiar condensation; these glands are either disposed in considerable number on or near the surface, in which case the secretion which they form is usually excreted from it, —or in the interior of the plant, where they are connected with the vascular system. It is not uncommon to find the glands entirely above the surface of the cuticle; in other instances they are surmounted with tubular hairs, which serve to excrete the fluids they elaborate; and occasionally they are mounted upon long hair-like stalks. The use of these structures is by no means apparent; sometimes they are evidently adapted to the defence of the plant, as in the nettle, the sting of which is composed of a

sharp tubular hair, with a poison gland at its base; and sometimes the viscid secretions, which are in this manner spread over the surface of the leaves, serve to attract and retain insects, as in the *Drosera* (Sun-dew). Besides the glands visible to the eye, there are doubtless many secreting points and surfaces which anatomical research has not yet revealed; and it cannot be doubted that membranes alone can perform the function. Thus, the little glands, as they are termed, with which the leaves of the Orange tribe and other aromatic plants are so copiously studded, are only single vesicles, of which the membrane secretes the volatile oil they contain. In fact, it is probably from the peculiar constitution of the membrane forming the vesicles of the glands previously described that their secreting powers are derived.

449. Amongst the principal secretions of this kind are the *resinous;* these are usually formed at numerous points in the surface of the leaves and bark, and are common to several natural orders, although peculiarly abundant in the Coniferæ. They have no tissue specially provided for their reception; but appear, by accumulating, to form regular tubular cavities, which are called turpentine vessels, but which are in reality nothing more than intercellular passages. *Volatile oils* are also found in the foliaceous and cortical parts of plants, and are contained in little cysts, generally of a rounded form, which are produced, like the turpentine vessels, by the separation of the adjoining cells. They may occur in many other situations, and are not uncommon in seeds or their envelopes. Heat and light seem peculiarly necessary for their formation; and they abound especially in tropical plants, and in those growing in open situations. It is to them that the variety of odours so widely diffused through the vegetable kingdom is to be attributed. When their receptacles are near the surface, and the surrounding tissue is soft and lax, the aromatic principles are constantly being exhaled to the atmosphere, and consequently are maintained only during the life of the plant, disappearing as fast as they are formed. There are many plants of which the perfume is only diffused at night, and this is peculiarly the case with flowers of dingy colour: amongst Orchideous plants, which generally exhibit this tendency, there is a remarkable exception to all rules, the *Cacalia septentrionalis*, which exhales an aromatic odour if exposed to the direct rays of the sun; but, if anything is interposed between it and the sun, its odour ceases, and is renewed as soon as the interference is removed. From the researches of Dumas it appears that most essential oils are not simple principles, as was formerly supposed, but compounds of camphor with liquid carburets of hydrogen; the latter being the peculiar constituent. The substance deposited by them after long standing, although slightly different according to the oil which yields it, always possesses the same essential character, and is nearly identical with camphor. This last product is itself a compound of oxygen with a base termed *camphene*, which

is essentially the same with pure oil of turpentine, and is composed of carbon and hydrogen alone.

450. When *fixed oils* occur in plants, they are not deposited in special forms of tissue, or in irregular cavities; but, like fecula, they occupy the interior of common cells. They are only found in the seed, or its envelopes; and they seem, like fecula, to be transformed by germination into a material fit for the nutrition of the young plant. They may be considered as performing, in the vegetable economy, a function analogous to that of fat in animals; but how it is made subservient to the processes of nutrition, we are yet in ignorance. In this light also we may regard some of the azotised principles found in plants; such as *gluten*, which is so abundant in the Cerealia (corn-grasses) and forms so large a part of the aliment of man. It is always found in combination with fecula; and from the observations of Raspail and Mirbel it would appear to form the membranous parietes of the cells in which the albumen is contained. The quantity of gluten contained in seeds varies considerably with the soil from which the plants are raised, and the manure applied to them. Thus, wheat without manure furnishes only 9 per cent. of gluten, and 70 per cent. of fecula; when manured with horse-dung, the proportions were $13\frac{1}{2}$ of gluten, and $61\frac{1}{2}$ of fecula; with ox-blood, 34 of gluten, and 41 of fecula; and, with still more highly-azotised animal products, 35 parts of gluten to 40 of fecula. Hence it would appear that the more azote is contained in the soil or manure, the more effectual it is in the production of gluten, which is increased at the expense of the fecula.

451. Of the numerous acid and alkaline secretions with which the vegetable kingdom supplies us, very little need be said; since, however important they are in a chemical or medicinal point of view, we know scarcely anything of their uses in the vegetable economy. One or two interesting facts respecting them may, however, be stated. From the property already mentioned (§ 350), which is possessed by gum, of being converted into sugar by the action of acids, it would seem that a process of this kind is effected during the ripening of fruits; for the gum and lignin they contain when unripe gives place to sugar, which, being formed by the action of the acid, corrects its taste, without its original quantity being diminished. A considerable amount of oxalate of lime is contained in many Lichens; and this appears to be generated in a very peculiar manner. A vast proportion of this tribe grow upon calcareous rocks; and, by the formation of oxalic acid (a compound of carbon and oxygen only) they act upon the lime-stone beneath them, and excavate for themselves hollows in it, which serve to retain the mould resulting from their decomposition, when their period of vitality is terminated. The same species of lichens, growing upon granite or other non-calcareous rocks, remain always at the surface, not having the power of acting chemically upon them. It is by means such as these that Lichens are the agents, as

formerly stated (§ 68), in converting the sterile and desolate rock into a scene of rich and luxuriant vegetation.

452. The means by which the principal colouring matter of plants, *chromule*, is produced have been already considered (§ 373, 4); but we may now advert to some of its peculiar modifications. Its usual form is that of small grains adhering to the insides of the cellules lying beneath the cuticle; and its composition has been stated by Macaire to be essentially carbon and hydrogen, with a small proportion of oxygen. In many cases it is altered during the succession of the seasons; most leaves changing to yellow in the Autumn, but some assuming a decidedly red tint. Macaire has ascertained that this change depends on the oxidation of the chromule,—the leaves continuing to absorb oxygen at night, but ceasing towards autumn to give it out during the day,—and that it may be artificially produced by acids, which turn the green first to yellow and then to red, according to the intensity of their action. The red colouring matter of many flowers, such as the *Salvia splendens*, exhibits the same properties as the chromule of leaves when oxidised; and this fact will be easily accounted for when it is remembered that all the parts of a flower are actively employed in the disengagement of carbonic acid and the absorption of oxygen (§ 381). As flowers are now well known to be but modifications of the same elementary structure which forms leaves, it would not seem improbable that they owe their varied colours to the same source,—a modification of chromule determined by the presence of free acid or alkali, or by the degree of oxidation it has undergone.*

453. Of the *Excretions* of plants, namely, those secretions which are formed for the purpose of being removed from the system, all that is certainly known tends to show that they may in general be reckoned as respectively similar to the peculiar products of the tribe. Thus, gum, sugar, oils, &c. are occasionally excreted, either from a mere excess of the quantity contained in the plant, or from their being formed near the surface. The *Fraxinella* secretes a volatile oil in little glands which are abundant on the leaves and stems; and the evaporation of the oil through the cuticle is so considerable in warm weather as not only to produce a powerful odour, but to render the atmosphere around the plant highly inflammable. The excretion of wax is very common in plants; and is frequently so abundant as to be important in an economical point of

* According to Messrs. Schubler and Funk, who published a memoir on this subject at Tubingen in 1825, the colours of all flowers may be divided into two grand series,—those of which *yellow* is the type, which is regarded is produced by chromule in an oxidised state; these are capable of passing into red or white, but never into blue:—and those of which *blue* is the type, in which they regard the chromule as having been deoxidised; these may also pass into red or white, but never into yellow. Others are of opinion, however, that there are at least two elementary colouring principles in plants, by the mixture and varieties of which is prepared all the brilliant and diversified spectacle we enjoy.

view. Sugar is excreted in the form of honey by the nectaries of many plants, as formerly noticed (§ 381); in this case it would seem to be but the overflow of that which is produced for a special purpose of the economy, but it serves the obvious purpose of alluring insects to facilitate the dispersion of the pollen; it is also occasionally excreted in a crystalline state. In addition to these instances of excretion, that of aqueous fluid should be noticed, which takes place from the leaves or foliaceous organs of many plants. Thus, the *Cæsalpina pluviosa*, a Brazilian tree, is said to produce a shower of drops of water resembling rain. The *Limnocharis Plumieri* has a large pore terminating the veins of the point of the leaf, from which water is constantly distilled; and a secretion of aqueous fluid takes place also from the leaves of the Arum, and several other plants. Allusion has already been made (§ 239) to the probability that part, at least, of the fluid contained in the pitchers of the Nepenthes, Sarracenia, &c. is secreted from the walls of the cavity; but it is not easy to determine the truth on this subject.

454. The last branch of the present enquiry, that which relates to excretions from the roots, seems likely to prove the most important one in an economical point of view, from its connection with agricultural processes. It is only recently that proper attention has been paid to the subject; and few experiments have been made upon it, except those of Macaire which were performed at the request of Decandolle. That plants have the power of freeing themselves in this manner from noxious ingredients introduced into their circulation, is shown by the following experiment. A plant of Mercurialis had its roots divided into two bundles, one of which was introduced into a weak solution of acetate of lead, whilst the other was immersed in pure water. At the end of a few days the water had become perceptibly impregnated with acetate of lead; which had therefore been taken into the circulation by the roots on one side of the plant, and thrown off again by the other set. Again, if a Leguminous plant be placed in distilled water, the fluid will be found in a few days strongly impregnated with mucilaginous matter excreted from the roots. The matters thus procured from plants of different families are very dissimilar, and seem closely allied in character to their proper juices. Thus the *Cichoraceæ* exude a large quantity of a brownish bitter secretion, analogous to opium; *Papaveraceæ* a substance of a similar nature; *Euphorbiaceæ* a gummy-resinous matter of acrid taste; and so on. From what has been formerly stated (§ 252), it would appear that this excretion, which is probably essential to the maintenance of the health of the economy, is also a necessary result of the conditions under which the function of absorption is performed. The mixture of the proper juices with the absorbed sap keeps up that superiority in its density to that of the external fluid which is required for the performance of *endosmose;*

while the transference of a portion of these juices to the liquid on the other side of the septum constitutes the *exosmose* which is always associated, more or less evidently, with it.

455. These facts will probably afford a rational basis for the principle which had been previously established by experience,—that a plant will not generally flourish in the earth which has been previously occupied by another of the same species. Thus, in gardens, no quantity of manure will enable one fruit tree to flourish on a spot from which another of the tribe has been removed; it is also a well established fact in forestry that, when a wood principally composed of one species of timber trees has been cleared, the trees which spring up spontaneously and supply the place of the former growth are for the most part of a different species; and all farmers practically evince, by the rotation of their crops, their experience of the existence of this law. The matter excreted from the roots may be easily proved to be injurious to the individual, or to others of the same species whose roots are placed in contact with it; but it has been suggested by Decandolle that the excretions of one species, genus, or family, may nevertheless be perfectly innocuous and even beneficial to those of another; thus, the Leguminosæ are well known to improve the ground for the Gramineæ to such a degree that it is absolutely preferable to obtain a crop of peas or beans between two crops of corn, rather than allow the land to lie fallow during the intermediate year. If this view be extended to the degree of which it seems capable, it may hereafter be possible for the farmer to dispense almost entirely with manure, by properly varying his successive crops, and thus making the excretions of one tribe of plants answer the purpose of a manure to another. There are some species, however, which may be said to poison all which come near them or succeed them; this seems particularly the case with such rank weeds as the Papaveraceæ, which are injurious, rather by the narcotic excretions of their roots, than by the exhaustion of the soil which they produce; and also with such species as excrete tannin, so that trees transplanted into a soil where oaks have previously grown seldom flourish and generally die. A very weak solution of opium placed in contact with the roots soon destroys the vital irritability of the plant; and tannin seems to operate in an equally injurious manner by its chemical action upon the delicate tissue of the spongioles (§ 250), and upon that of the general vascular system of the plant, when introduced into it. Macaire has proved that excretions by the roots take place rather under the influence of obscurity than of light; and that they are strictly dependent upon the vitality of the plant and the energetic action of its nutritive system.

With regard to the immediate function of secretion in the vegetable economy, we have been obliged to confess the ignorance which

prevails amongst physiologists as to the object of the greater number of the changes included in it. But we must not overlook their obvious uses to the Animal creation. How many of the products of secretion constitute the most important and agreeable articles of food both to man and the inferior tribes! How many more gratify the senses by their fragrant odours, or the delicacy and variety of their tints; and how numerous are the means which they afford for the restoration of the body in disease, by their medicinal effects upon the system! This is an instance in which a very cautious application of the doctrine of final causes is necessary. No one ought to be presumptuous enough to affirm that though he has discovered an evident purpose in a particular structure, or an obvious end to be answered by a particular function, there may not be some other, less apparent, but really of more consequence; nor when he is altogether at fault as to the design for which some organ seemingly useless, may have been created, or the object for which some function with no evident purpose may have been introduced into the economy, has he any right to say that their existence is unintelligible or superfluous. On the contrary, their very universality and regularity are but indications of our own ignorance, as contrasted with the Infinite Wisdom of the great Being who made nothing in vain.

Secretion in Animals.

456. The complication of the general nutritive processes in the higher classes of this kingdom involves a great increase in the extent and importance of the secreting system, and in the variety of the products separated from the circulating fluid. In all cases, the secretion is formed by a special organ or *gland*, more or less complicated in structure; in its simplest or essential character, however, it may be regarded as a bag or sac, formed of a membrane on the outside of which blood-vessels ramify, and provided with an orifice by which the contents may be either transmitted to the place where their presence is required, or carried out of the system altogether. It is the membrane of which this sac is formed that constitutes the true secreting organ; and although our means of observation do not at present enable us to distinguish any marked differences in its structure in the different glands, it is manifest that such variations must exist, since (as will presently appear) the conformation of the secreting sacs or tubes into masses of various shape and texture has nothing to do with the character of their products,—this being entirely determined by that of the membrane through which they are transuded from the blood. It is not a little curious to remark, also, that all the secreting membranes of which glands are formed are prolongations either of the skin or of the mucous membranes which are continuations of it. And in tracing the gradual evolution of the secreting system in the animal scale, we shall have peculiar opportunity

of observing and applying the principle of *specialisation*, which has been already so frequently dwelt upon.

457. But these glands are not the only organs of secretion; for a more general condition of this function may be traced throughout the Animal, as in the vegetable kingdom. In the cellular tissue, wherever it exists, there appears to reside a power of rapidly separating from the blood its serous or watery portion; and it is upon the due distention of the interstices between its elastic fibres with this fluid, that the peculiar tension or *tonicity*, which characterises this tissue in its healthy state, appears to depend (§ 35). A secretion of a more peculiar nature is formed by one of the modifications of cellular tissue, the *adipose*, the fatty matter which its vesicles contain being strictly a secretion from the membrane forming their walls; and as these cells have no outlet, their contents are stored up in them, like the corresponding secretions of plants, until their re-absorption is required for the purposes of the economy. There are other cases in which secretion takes place into closed cavities, and this frequently upon a large scale. Thus, the synovial capsule, which surrounds the joints and covers the articular surfaces (§ 36), may be demonstrated to be a completely closed bag or sac; and a fluid is secreted from its inner surface, that lubricates the parts of which the friction would otherwise be injurious, but is never poured forth by any outlet; so that in disease it sometimes accumulates and distends the sac. In like manner, the heart, lungs, and intestines are each surrounded by a serous sac, the inner walls of which secrete a lubricating fluid, by which the motions of these parts are prevented from being injurious to the surrounding organs; and here too the continued effusion of the natural secretion unbalanced by its absorption, or an excess of it from disease, may cause that degree of accumulation which constitutes dropsy of the thoracic or abdominal cavities. There are a few instances in which secretions, afterwards to be used elsewhere, are formed in closed cells; and they then escape from their confinement by bursting their envelope.*

458. In the different glands possessed by the higher animals, we may find types of all the gradations of structure which the most complex (such as the liver) exhibits when its evolution is traced, either in the ascending scale of the animal kingdom, or in the development of the fœtus,—the same correspondence which has been elsewhere noticed being peculiarly obvious here. It will be our most advantageous plan, therefore, to describe the principal forms under which glands exist, previously to giving a general sketch of the condition of the secreting function in the different classes; for, in this manner, are we able to analyse and render evident much that would otherwise be almost unintelligible from its complexity. The simplest form of gland is a mere bag composed of membrane, and having an orifice for the discharge of its contents. This

* See Müller's Physiology, vol. i. p. 431.

bag may be of very different forms; sometimes it is globular, sometimes elongated into a short tube. Examples of this structure are very frequent. Thus, the *mucous crypts* which are so abundant on the surface of all the mucous membranes (§ 38), may be regarded as the first indication of it. In many animals, the follicles of the skin, by which its protective secretion is formed, exhibit it very distinctly; at Fig. 155 is represented one of the flask-shaped follicles in the integument of the Salamander. In Birds, the gastric secretion by which the food is moistened in the ventriculus succenturiatus (§ 277) is poured out by similar follicles closely arranged in its lining, and somewhat prolonged into a tubular form, as at Fig. 154. These are illustrations drawn from the minor portions of the secreting system in the higher animals; but those glands which, in point of complexity and importance, hold the highest rank, present a condition precisely analogous when examined sufficiently low down in the scale; and, in fact, every gland may be found to possess this structure if examined in the members of that class in which it makes its first appearance. Thus, in the class of FISHES, the *pancreas* occasionally shows itself in the form usually exhibited by higher Vertebrata; in some species, however, it is much more simple; and in the CEPHALOPODA, where this gland makes its first appearance, it may be detected as a simple globular or oval sac opening into the alimentary canal, or as a prolonged tube, possessing a blind termination, and sometimes twisted spirally for closer packing, as in the Sepia, Loligo, &c. Fig. 156. This last form is interesting as being the evident connection between the globular follicle and the lengthened tube which constitutes other glands. Even the liver in many among the lowest classes is represented only by a series of such follicles, either contained within the coats of the stomach, as in the Ciliobrachiate Polypi (§ 119), or arranged round the intestine, opening into it by many distinct orifices—like the follicles of the bulbus glandulosus of Birds—as in many Insects (Fig. 157). In some of these follicles a tendency to subdivision is manifested, as in Fig. 158; and, either in this manner, or by the junction of distinct sacs, *aggregate or compound follicles* are formed, several having their orifices united into a common outlet, or into a tube which conveys their products to it.

459. The arrangement of these aggregate follicles is extremely various. Thus, at Fig. 159 is shown the manner in which they cluster together to form one of the glands in the stomach of the Beaver; and the Pancreas in many fishes, the liver in several Insects, the mammary gland of the Ornithorhyncus, and other subordinate glands in higher Mammalia (Fig. 161) are found to possess the same type of structure. In other cases the follicles are arranged upon their common duct, like currants upon their stalk; very beautiful examples of this occur in the Meibomian glands of the eyelids (Fig. 162), the salivary glands of many animals, the poison glands and those connected with the reproductive function in

insects (Fig. 163), and many others. All these follicles may, it is evident, be regarded as dilatations of the tube into which they open, as that tube may itself be considered a prolongation of the surface from which it proceeds. It is easy to see how the intricacy of the structure may be increased by further subdivision of the secreting cavities,—while their essential simplicity still remains evident. Thus, in Fig. 165 is shown a portion of the liver of the Lobster, which is seen to consist of a number of elongated follicles, disposed upon a tube which is itself only a branch of the main canal. In like manner, the salivary glands of the higher Mammalia are formed by the subdivision of the branches of the principal ducts, as shown in Fig. 166. In these and similar instances, the collection of the secreting vesicles round the separate branches of the duct gives rise to the division of the gland into *lobules*, the proportion of which to its whole bulk will depend upon the minuteness of the ramification of the duct, previously to its termination in the secreting cœca. Thus, in the liver of the *Pagurus striatus* (one of the Hermit-Crabs), of which part is shown in Fig. 164, these lobules are very distinct; and though they appear to be solid, a more careful examination shows that they are channelled out into secreting cavities that open into the branch of the duct on which they are situated. A corresponding structure exists in the mammary glands of many Mammalia (Fig. 167). In the liver of the higher Vertebrata, these terminal lobules are very minute, and have received the name of *acini;* but although in the adult condition it has not been found possible to trace (in the healthy state at least*), the minor subdivisions of the hepatic duct, to their termination in the acini, no doubt exists that those bodies are formed by the prolongation of these branches into secreting sacs, like those elsewhere found. In the Squirrel, indeed, these prolongations may be distinctly seen, the blind sacs being cylindrical in form and closely packed together (Fig. 168); and in the embryo condition of many Birds and Mammalia, they are beautifully manifested. It is evident, then, that all the forms of glands yet described are but modifications or repetitions of the simple type first described; and, exactly as in the case of the lungs (§ 413), do we find that, in proportion to the activity of the function and the elevation of the being in the scale, the structure of the organ becomes more intricate, through the minuteness of the subdivision of its parts, which allows an increase of surface to almost any extent without a corresponding increase of bulk, its essential character remaining unchanged.

* Certain diseased conditions occasionally lead to disclosure of the intimate structure of parts, much more complete than that effected by the knife and microscope of the anatomist. Thus, in the "North American Archives of Medical and Surgical Science," No. 9, is related a case in which obstruction of the excretory duct of the liver produced such an enormous dilatation of all its ramifications with the secreted fluid, that their termination in blind extremities in the intimate tissue of the gland was distinctly exhibited. These blind extremities were closely clustered together, and the ducts proceeding from them were seen to converge, and to terminate in the main trunk for the corresponding lobe.

460. It is not a little curious that—while the required extent of surface is given in all the glands connected with the alimentary canal by the subdivision and ramification of the duct itself, the cœcal terminations being still short and simple,—it is obtained in the kidney and glands peculiarly connected with the reproductive system by the prolongation of the follicles themselves into tubes of enormous length, which maintain the same diameter through the greatest part of their course, and do not ramify, or at least very slightly; but which are convoluted or rolled upon one another in such a manner as to occupy very little space. Thus, in INSECTS, in which class what were formerly regarded as *biliary* are now considered *urinary* tubes (their secretion being shown to contain urea § 273), we find the simplest possible form of an apparatus of this kind (Fig. 105), the separate canals opening into the intestine by distinct orifices. The difference between a prolonged tube of this kind and a short rounded vesicle, is, however, more apparent than real. It is on the exterior of both that the blood-vessels ramify from which the secretion is elaborated by the membrane composing them; and each conveys the fluid poured into its cavity to the orifice by which it is discharged. A precisely similar gradation may be traced in the evolution of glands of this character, with that which has been already described regarding the development of the other. Thus, the kidney of Fishes consists of a congeries of simple tubes, sometimes nearly straight and parallel, sometimes convoluted, which take their organ from the ureter. Where the kidney has a lobulated aspect, each lobe consists of the convolutions of a single tube. In Serpents and other Reptiles a further complication is observed, the ureter giving off successive branches, and each of these subdividing into a number of similar prolonged and convoluted tubes, which altogether make up the lobule. Fig. 169 exhibits this structure in a Coluber, and also shows the relation of the secreting tubes to the blood-vessels which ramify between them. In the higher Mammalia, the lobuli, which are disposed upon a similar though still more intricate plan, are all united together, and form, with the plexus of blood-vessels that surrounds them, the *cortical* substance of the kidney. Their convoluted tubes terminate in straight excretory ducts, and these empty themselves at last into the ureter.

461. From the preceding details it will appear that the substance of every gland is made up simply of the ramifications of the duct, which is itself a prolongation of the surface upon which it terminates,—and of the plexus of vessels which surrounds these tubes and sacs, and connects them with one another. The distribution of the artery upon the secreting sacs of a loosely-aggregated gland (the parotid) is seen in Fig. 166; but in those of closer texture, such as the liver, the arrangement is more complex. It will be recollected that the secretion of this gland is formed, not from arterial blood, as in other cases, but from the blood which has been already rendered venous by circulating through the abdominal

viscera (§ 309). The ramifications of the *vena porta*, therefore, are those which are concerned in this function, those of the hepatic artery serving only to nourish the tissues; whilst the hepatic vein collects the blood from both. It appears from the investigations of Mr. Kiernan* that the terminal branches of the vena porta compose the exterior of each lobule, while the hepatic vein takes its origin in the centre; the capillaries which communicate between these being distributed on the membrane of the secreting cœca. In Fig. 171 is seen Mr. K.'s representation of this arrangement.†

462. We may now take a brief survey of the evolution of the secreting system in general, observed in ascending the Animal scale. No special organ distinctly adapted to this purpose can be shown to exist in the lowest classes. Wherever there is a stomach, however, for the digestion of food, some secretion must be formed by its coats for the purpose of that solution which is the necessary preparation for the absorbent process. We may, therefore, not improbably regard the whole of the interior surface of the digestive cavity of the *Hydra* as possessing this power; and where this cavity is more complex in its form, as in the *Star-fish*, *Planaria*, &c., being provided with a number of cœcal prolongations, it would seem not impossible that some of these may have a particular adaptation to this purpose. The rudimentary condition of the *Liver* in some Polypes and Annelida has already been noticed. Among the INSECT tribes it attains greater development; but it would seem altogether subordinate to the urinary system, which has been erroneously considered a portion of it. It is not difficult to account for the low condition of the liver in these classes; since the excessive amount of the respiratory function must render almost unnecessary any other method of discharging carbon from the system. It is not among all the Articulata, however, that the liver appears a subordinate organ; for in the CRUSTACEA, whose respiration is aquatic and therefore less energetic, it attains a very considerable size, occupying frequently a large part of the abdomen, and in one or two species acquiring a spongy texture by the union of its minute subdivisions into one mass, so as to resemble in some degree the solid form which this gland presents in higher animals (Fig. 164). The liver

* Philos. Trans., 1833.

† The ingenious experiments of Mr. Kiernan have shown that various appearances of the liver after death may be readily accounted for by attending to this relation. Thus, if the hepatic veins be filled with red injection, the centre only of the acini will be filled; if the vena porta alone be injected, the circumference only will be coloured by it. In either case, the liver will present a mottled appearance from the mixture of red with its ordinary yellow; but in the one case each acinus will have a red centre with a lighter border, and in the other a red circumference with a pale centre; and these are the appearances which naturally result from a congested state of one or other of these systems at the time of death. If neither is congested, the whole liver is pale; if both are distended, the whole is dark; and sometimes the opposite colouring is met with in different parts of the same liver.

usually presents in the MOLLUSCA a very large size and highly developed condition; and although this is, without doubt, in part connected with the general complication of the digestive functions in these classes (§ 274), yet we may also fairly regard it as a compensation for their feeble respiratory powers. It would be interesting to trace in detail the gradual elevation in the character of this organ, which may be perceived in ascending through these classes; but it must here be only stated that, whilst in the TUNICATA it is disposed in many separate lobes around the pyloric orifice of the stomach, and opens into that cavity by numerous apertures, it is concentrated in the CEPHALOPODA into one mass, and opens into the intestine (or rather enters a prolongation of it which may be regarded as part of the pancreas) by a single duct. In FISHES we find the earliest appearance of the gall-bladder, which may be regarded as a dilatation of the excretory duct serving the purpose of a receptacle for the fluid as secreted, and thus allowing its passage into the intestinal tube only when required for the purposes of digestion. The gradually-increased complexity of the structure of this gland in the Vertebrated classes has already been noticed (§ 459). In the MAMMALIA the liver generally possesses considerable development, and pours its secretion into the intestine by a single duct; sometimes, however, there are several excretory canals, of which one terminates in the intestine, and the rest in the gall-bladder; and there are species among all classes of Vertebrata in which the gall-bladder is entirely absent,—a deficiency that is most common in herbivorous animals, in which the process of digestion is almost constantly going on.

463. That the *bile* is principally secreted from the venous blood brought to the liver by the vena porta (§ 309), there would seem good reason to believe; but, as its formation continues, though in diminished quantity, after this vessel has been tied, it would appear that the arterial capillaries must also be concerned in it. It is not improbable that one office of the liver may be to purify the blood from any injurious matter taken in from without, as well as to free it from that which has been taken up in the course of the circulation. It has been stated as probable (§ 275) that most of the substances absorbed from the intestinal surface, which do not enter into the constitution of the chyle, are introduced by the mesenteric veins; and all these unite into the portal trunk, so as to submit the blood which has received any such admixture to the action of the liver, before it is transmitted to the system at large. And if, as is believed by many, there is an actual exchange of ingredients between the blood and the chyle in the lymphatic glands, a part of the materials taken up by the lacteals will be similarly treated.* The probable uses of the

* It is an interesting fact in relation to this hypothesis, that in animals poisoned by repeated doses of salts of copper, the metal has been traced in the liver after death, although it could not be detected in other parts of the body. See Dr. Christison's Treatise on Poisons.

secretion of bile in the digestive process have already been stated (§ 262). As to its constitution it is difficult to speak positively, since chemists disagree much respecting it. The solid resinous matter, which may be obtained by evaporation, consists almost entirely of carbon and oxygen (the proportions being about $55\frac{1}{2}$ of carbon, and $43\frac{1}{2}$ of oxygen, to 2 of hydrogen),—nitrogen being entirely absent. From this substance two principles may be obtained, which probably exist in a corresponding state in fluid bile. These are *cholesterine*, a crystalline fatty matter, resembling spermaceti in appearance, and forming a large proportion of biliary concretions;—and *picromel*, a compound to which the peculiar taste of the bile is owing, and which also may be reduced to a crystalline form. Of these, the first is by no means peculiar to bile, and has been found in many other fluids of the body, especially those drawn from morbid parts; but its deposition in them may not improbably result from the constant presence of it in the blood. It is suggested by Berzelius that the greatest part of the animal matter of the bile may be regarded as an altered form of albumen; and it is not unreasonable to surmise that its tendency to assume a crystalline form is the cause of its unfitness to serve for the general nutrition of the system, and consequently necessitates its excretion. The retention of the bile within the system, from any obstruction to its flow through the ducts, is well known to produce very injurious effects; the secretion is then absorbed again into the blood, giving rise to jaundice; and the injury to the properties of the vital fluid thus produced is marked by a peculiar inaptitude for muscular or mental exertion. The entire cessation of the process of secretion itself is followed, however, by a more severe train of symptoms, and usually terminates in death. In cases of this kind the bile-ducts are found pervious and empty.

464. The *Pancreas* (sweetbread) cannot be regarded as holding a place in order of importance nearly as high as that of the liver; since we find it nearly or wholly absent in all the Invertebrata; and since experiment shows that it may be removed from animals which possess it without materially affecting their health. The secretion which it forms would seem to be of more consequence to the digestive process than to the purification of the blood; for it differs but little in composition from saliva, and might, in fact, be regarded as a more concentrated form of the same fluid. The advance in the complication of the form of this gland, as it may be traced in ascending the animal scale, exactly corresponds with what has been already stated regarding the structure of glands in general. In the CEPHALOPODA it usually exists as a single sac, sometimes globular, and sometimes prolonged into a straight or spiral tube (§ 458). Its interior is in general partly divided by folds of the lining membrane; and in FISHES we frequently meet with many cœca, instead of a single subdivided one. These again subdivide and ramify, so as to increase the

extent of secreting surface; and in the *Sturgeon*, the tubes are united together so as to form a sponge-like cellular mass; whilst in the *Sharks* and *Rays* the organ attains the close texture which it possesses in higher animals.

465. The secretion formed by the *Kidneys* may be regarded as possessing a purely excrementitious character, since it serves no useful purpose in the economy, and its separation appears essential to the maintenance of the vital properties of the blood. This gland almost always presents a tubular structure; and the required extent of surface is given by an enormous prolongation of the individual cœca, not by a multiplication in their number by minute subdivisions as in other cases. It is here, therefore, very evident that the whole of the secreting surface is but a prolongation of the duct in which all the tubes terminate; and, as the walls of this duct are themselves continuous with the membrane on which it opens, it is obvious that, however prolonged or ramified this surface may be, it is a part of the general system of mucous membranes, of which some modification constitutes not only the external tegument of the body but every reflexion of it. The justice of this view will be still further demonstrated when the embryonic development of the glands is described (§ 472). The form in which the urinary organs exist in INSECTS has been already noticed (§ 460). No very decided traces of them have been found among the MOLLUSCA; but uric acid, a characteristic ingredient of the fluid, has been detected in the contents of certain glandular sacs which are usually situated near the outlet of the mantle, and which seem to secrete the colouring matter of the shell. In the *Janthina* (§ 101) the purple fluid which tinges the shell, and which is sometimes excreted as a means of defence, appears to hold this place; and the same may be said of the ink of the naked CEPHALOPODA. Throughout the Vertebrated classes, the kidney presents a very similar character, consisting of immensely prolonged tubes, on the walls of which blood-vessels ramify, and which are closed at one extremity, and terminate at the other in the branches of the excretory duct. It is in the closeness of the arrangement and the minuteness of the ramification of the blood-vessels upon the walls, that the principal difference exists in the structure of this organ in different classes of VERTEBRATA. In some of the higher ARTICULATA, a slight dilatation of the urinary ducts near their termination may be perceived,—the first indication of a urinary bladder for the temporary reception of the excretion. A small cavity of this kind is found in some FISHES. Among the REPTILES, it attains its greatest development in the *Chelonia*, in which, as in the *Batrachia*, it is very large and constant; whilst it is often absent in the *Sauria*; and no trace of it exists in *Serpents*. In BIRDS also it is undeveloped, except in the *Ostrich*, where a dilatation of the lower part of the intestine, into which the ureters open,

serves this purpose,—thus marking, with many similar points of structure, the affinity of this animal with the MAMMALIA, in which the urinary bladder is constantly found.

466. The secretion of urine appears to be the principal means by which the superfluous nitrogen of the system is got rid of; for the principal part of its solid contents, exclusive of the saline matter (which corresponds with that of the blood), consists of very highly azotised principles. Of these the most characteristic is *urea*, which, when pure, appears in the form of delicate acicular crystals, and contains nearly 47 per cent. of nitrogen,—a larger proportion than that known to exist in any other organic substance. *Uric acid*, which exists in small proportion in health, but of which the quantity is much increased in many diseases, also contains one-third part of nitrogen; and it is probably to be regarded as a compound of urea, which principle may be obtained from it. Here again, therefore, we see a provision made for the excretion of the *crystalline* matter which results from the changes that take place in the blood during the circulation, and which is highly deleterious if retained in the system. It is an interesting fact in relation to the source of this excretion, that in the serum of blood (§365) there is portion not coagulable by heat, &c., which is termed the *serosity*. This contains a large quantity of animal matter, which may be reasonably supposed to consist principally of effete particles, since it increases in amount when the kidneys are extirpated; and when the secretion is checked by this operation, or by natural disease (as not unfrequently occurs), urea may be detected in this part of the blood. The effects of the retention within the current of the circulation of the matter which should have been thus removed from it, are very speedily fatal; the brain appearing chiefly to suffer. The aqueous portion of the secretion is very variable in amount in different classes; being sometimes nearly deficient, as in Birds and Serpents,—and sometimes very abundant, as in the Chelonia. It is generally greatest when the amount of transpiration from the skin is least, and seems to be in some degree vicarious with that excretion. The highly-azotised products which are generally so abundant in the urine of carnivorous animals, are often very scantily present in the vegetable-feeders.

467. The general distribution of the *Salivary* glands in the animal scale has already been noticed (CHAP. V.). They are usually developed in proportion to the solidity of the food and the degree of mastication it undergoes; but the character of their structure always bears a relation with the place of the being in the animal scale. Thus, in many INSECTS, whose mandibles are actively employed upon hard food, the salivary secretion is very important; but the required extent of secreting surface is given, as in the respiratory apparatus (§ 394), by a prolongation of the simple tubes of which the gland usually consists in the Articulated classes, and not by any transition to the more concentrated form which it presents

in higher tribes. In the MOLLUSCA, these glands, like the others appertaining to the digestive system, acquire an increased importance, and attain a higher grade of development, manifested in their more solid and united texture. In the highest form in which the salivary glands exist in the VERTEBRATA, however, they always retain a type much simpler than that of more important glands (§ 459); resembling, in fact, that which the liver and pancreas present in inferior classes. The amount of solid matter held in solution in saliva is not more than about 1 per cent.; and this consists partly of animal matter (much of which seems to be a modification of albumen), and partly of saline ingredients derived from the blood. A few transparent globules may be observed in the fluid; and these are stated to be larger than the red particles of the blood. The secretion of saliva appears, like that of tears, to be peculiarly under the influence of the nervous system. Every one knows how much it is affected by states of mind, aud especially by emotions excited by the presence or conception of food. But it must also be through a similar channel that the secretion is excited by the contact of substances introduced into the mouth, without the intervention of any mental process; since the glands are situated at a distance from the surface stimulated, and not immediately beneath it, as in the stomach.

468. The protective secretions of the skin deserve notice on account of their very extensive occurrence under some form or other throughout all classes of animals possessed of a soft external tegument. In most of those which inhabit salt water, there is a very abundant secretion of mucus from the surface; and, in many of the lower tribes, this mucus has a luminous property, and sometimes a very acrid character, both of which may be useful in self-defence (§ 476). The mucous secretion is most abundant in FISHES, where the glands by which it is formed attain considerable extent of development; and some of the *Batrachia* also are furnished with a similar protection to their soft skins; in neither case, however, does the secreting apparatus possess a higher character than that of the less-developed mucous follicles of the skin of higher animals (Fig. 155). Many peculiar secretions, however, occur among species of various classes, which may be regarded as modifications of the general cutaneous mucus. Thus, strongly odoriferous fluids are generated by many Insects, Reptiles, and Mammalia; and these are sometimes produced by insulated glands, as in the Castor, Musk-Ox, &c., and sometimes from the general surface or a large part of it. The oily secretion, again, which serves so important a purpose in the economy of the diving Birds (in rendering their downy covering impervious to water) may be regarded as belonging to the same general division.

469. The *Lachrymal* and *Mammary* secretions are more restricted; the former not being formed by any Invertebrata, and being nearly deficient in Fishes; and the latter existing in no class but the Mammalia.

The glands which form them never attain a very concentrated type, their ultimate cells remaining large. Both these secretions are capable of being peculiarly influenced through the nervous system, either by particular states of mind, or by a stimulus sympathetically communicated from another organ. Thus, although a constant secretion of tears takes place for the purpose of lubricating the eye, an increased flow may result from mental emotion, or from an irritation of the surface of the ball, of which the mind is not necessarily conscious. The secretion of milk is influenced in like manner. How this sympathetic irritation is conveyed will be hereafter enquired (§ 595).

470. It would be foreign to the purpose of this work to enter into further detail on the various peculiar secretions which are met with in different species of animals. It may be desirable, however, again to direct attention to the fact already noticed (§ 39) that the *epidermis* and all its appendages, which constitute the various forms of the *dermo-skeleton* (§ 82), are to be regarded as secretions from that modification of mucous membrane which constitutes the true skin. And here, as elsewhere, we are led to admire the number of purposes which the same simple elements may be made to serve. It will be interesting to compare the dimensions of some of the ultimate portions of the glands of different animals; by which it will be seen that the simpler the character of the gland, and the lower in the scale it is examined, the larger in proportion to the size of the animal are its elementary parts. The following measurements are given in fractions of an inch:—

Capillary vessels in Man	$\frac{1}{4700}$	to	$\frac{1}{1590}$
Pulmonary air-cells	$\frac{1}{199}$	to	$\frac{1}{69}$
Cells of the liver of *Murex* (Gasteropodous Mollusc)	$\frac{1}{72}$	to	$\frac{1}{48}$
———— *Helix pomatia* (garden snail)			$\frac{1}{163}$
———— embryo of Jay (1 inch in length)			$\frac{1}{544}$
———— embryo of Rabbit	$\frac{1}{854}$	to	$\frac{1}{791}$
Tubuli uriniferi of electric Ray			$\frac{1}{194}$
———— Serpent			$\frac{1}{388}$
———— Owl			$\frac{1}{543}$
———— Squirrel			$\frac{1}{619}$
———— Man	$\frac{1}{923}$	to	$\frac{1}{512}$
Cells of salivary gland of Murex	$\frac{1}{72}$	to	$\frac{1}{60}$
———— Goose			$\frac{1}{355}$
———— Dog			$\frac{1}{493}$
Vesicles of lachrymal gland of Goose			$\frac{1}{310}$
Vesicles of mammary gland of Hedgehog during lactation	$\frac{1}{129}$	to	$\frac{1}{99}$

471. Although, as we have seen, the number and variety of the secretions becomes greater in proportion to the increased complexity of the

nutritive processes in the higher classes, and although each appears as if it could be formed by its own organ alone, yet we may observe even in the highest animals some traces of the community of function which characterises the general surface of the lowest. It has been shown that, although the products of secretion are so different, the elementary structure of all glands is the same;—that the secreting surface may be regarded, in every instance, as a prolongation of the general envelope of the body, or of the reflexion of it that lines the digestive cavity;—and that the peculiar principles of the excretions seem to pre-exist in the blood, in a form at least closely allied to that which they assume after their separation. It would result, then, from the general law formerly stated (§ 201) that when the function of any particular gland is suspended, or where it is not performed with sufficient activity to separate all the products to be excreted from the blood, the general surface, or other secreting organs, should be able to perform it in some degree; and pathological observation is constantly bringing to light examples of such an occurrence. Thus, cholesterine has been found deposited in diseased tissues of almost every part of the body; uric acid in the neighbourhood of the joints; urine has passed off from the skin, stomach, intestines, nose, and mamma, and has been effused into the ventricles of the brain; and milk has been poured forth from pustules on the skin, and from the salivary glands, kidneys, &c. Such cases have been regarded as fabulous; but the physiologist can now readily comprehend them.

472. The last division of our subject is the evolution of the secreting organs in the embryo state. The details on this point have been most ably worked out by Müller* and others; and it has been shown that a most beautiful correspondence exists between the character of each gland in the higher animals at different epochs in its development, and the permanent forms it exhibits in the lower. The general facts relating to the formation of the glands connected with the alimentary canal (such as the liver and pancreas) may be briefly stated. The glandular mass is at first gelatinous and translucent, like all the rest of the tissues of the embryo, and appears as a projection of the mucous membrane of the alimentary tube, with which it is in proximity; but as yet it contains no cavity (Fig. 172, A). After a time, the surface becomes lobed and uneven, and a hollow is formed in the interior by a depression of the mucous membrane into its substance (B). This cavity is at first quite simple, like the simplest biliary follicle among the Acrita; but, as the exterior becomes lobed, the cavity sends a prolongation lined by mucous membrane into each division; and thus is gradually formed the complex apparatus of ramifying tubes and cœca which ultimately presents itself (C). It appears, however, that in some instances the secondary cœca are formed before their communication with the primary cavity, and that they gradually connect

* In his splendid work "De penitiori structurâ glandularum."

themselves with it,—just as the capillary blood-vessels are formed before the main trunks. In proportion as the tubes are extended, and the blood-vessels ramify among them, the original plastic substance disappears, or remains as cellular tissue only, connecting the lobules. And on the degree of proximity of the lobules, and the amount of this connecting cellular tissue, will be the final solidity of the structure. At Fig. 173 is seen a section of the parotid gland in the embryo of the sheep, in which its very simple structure, consisting of a ramifying cavity hollowed out of the plastic mass, is well exhibited, and may be contrasted with its permanent form seen in Fig. 166. The relative size and degree of development of the different glands in the fœtus bears an obvious relation to the conditions of embryonic life; thus, the liver possesses a very large size, occupying the whole of the abdomen, since it is then the principal if not the only organ capable of decarbonising the blood.

CHAPTER XII.

EVOLUTION OF LIGHT, HEAT, AND ELECTRICITY.

Evolution of Light in Vegetables.

473. So little is known of the causes or purposes of the evolution of Light which is no unfrequent occurrence amongst organised beings, of the lower classes especially, that it would be useless to speculate upon them. It is well however to bring together the principal facts relating to the phenomenon itself, and the conditions of its occurrence. It has been stated that many flowers, especially those of an orange colour, such as the *Tropæolum majus* (nasturtium), *Calendula officinalis* (marigold), *Helianthus annuus* (sun-flower), &c., disengage light in serene and warm summer evenings, sometimes in the form of sparks, sometimes of a more feeble and uniform character; but many physiologists are disposed to question these assertions, from their not having been able to witness the phenomena. There is no doubt, however, that light is emitted by many Fungi, especially various species of *Rhizomorpha;* and in some instances to a very considerable extent. The light is perceived in all parts of the plant, but chiefly in the young white shoots; and it is more vivid in young than in old plants. The phosphorescence is stronger in such as grow in the moist and warm localities of mines, than in those inhabiting dry and cold situations. It ceases if the plant be placed in vacuo, or in any atmosphere

which does not contain oxygen; but reappears when it is restored to the air, even after remaining for some hours in vacuo or in azote. No phosphorescence is perceived after the death of the plant. The only other phenomenon connected with vegetable phosphorescence which is worth notice is one stated by Martius, that the juice of the *Euphorbia phosphorea*, a Brazilian plant, emits light, especially when heated. Considering that in all the circumstances mentioned, the combination of carbon and oxygen is taking place to a considerable extent, it seems difficult to believe that there is not some connexion between the phenomena; but no speculation can yet be raised on the subject, with any prospect of stability, from the want of sufficient facts as its basis. An evolution of light has frequently been observed to take place from dead and decaying wood of various kinds, particularly that of roots; it seems connected with the conversion of oxygen into carbonic acid, but is not increased when the substance is placed in pure oxygen. Decomposing fungi, also, frequently exhibit luminosity; but this is very different from that displayed by some of that tribe during their living state.

Evolution of Light in Animals.

474. A large proportion of the lower classes of aquatic Animals possess the property of luminosity in a greater or less degree. The phosphorescence of the sea which has been observed in every zone, but more remarkably between the tropics, is due to this cause. When a vessel ploughs the ocean during the night, the waves,—especially those in her wake, or those which have beaten against her sides—exhibit a diffused lustre, interspersed here and there by stars or ribbands of more intense brilliance. The uniform diffused light is partly emitted by innumerable minute animalcules which abound in the waters of the surface; and these, if taken up into a glass vessel, continue to exhibit it, especially when the fluid is agitated. This phosphorescence continues only during the life of the animals; the addition of a little sulphuric acid to the water causes them to emit a very brilliant and sudden light for an instant, and it then ceases, in consequence of their death. All the *Medusæ*, especially those of tropical seas, appear to be phosphorescent; the light is emitted, particularly round the tentacula, during the movements of the animal; and it seems to proceed from a mucus secreted from the surface, which may continue to exhibit the same property for a time when removed from it. This mucus, which has a very acrid character when applied to the human skin, communicates to it a phosphorescent property; and when mixed with water or milk, it renders these fluids luminous for some hours, particularly when they are warmed and agitated. From this source it is probable that the diffused phosphorescence of the sea is partly derived, whilst the brilliant stars and ribands with which the surface is bespangled indicate the presence of the larger tenants of the deep. Similar luminosity is possessed by

many of the marine ANNELIDA, as the *Nereis;* and by some MOLLUSCA, as *Pholades*, *Salpæ*, *Pyrosomata*, &c. In all these the general phenomena are analogous, the luminous matter appearing to be a secretion from the surface of the animals, which communicates its peculiar property to water or solid substances that come in contact with it. The light disappears in vacuo, but reappears in air; it is increased by moderate heat, and gently stimulating fluids; whilst a cold or boiling temperature, or strong stimulants, soon extinguish it. It continues for some days after death, but ceases at the commencement of putrefaction. Other marine animals of higher classes are possessed of similar properties; thus, many CRUSTACEA are known to emit light: and the same power has been attributed to FISHES. It is not improbable that with regard to the latter there has been a partial deception, arising from the excitement given by their movements to the sources of phosphorescence in the surrounding water; late observations, however, lead to the belief that, in some species of fish, there is an inherent luminosity.

475. In all the instances hitherto mentioned, the evolution of light proceeds from the general surface of the body, and sometimes also from its internal prolongations (as the respiratory tubes); in the cases next to be described, the luminosity is concentrated upon some particular portion, and frequently in minute points. This occurs in many species of the class INSECTS; the light emitted by which, from that of the quiet Glow-worm of temperate climates, to the more startling brilliancy of the Fire-flies of warmer regions, has been a fruitful theme for poets and philosophers in all ages. The luminous insects are most numerous among the *beetle* tribe, though some of the most brilliant belong to ather orders. In the glow-worms *(Lampyris noctiluca* and *Lam. splendidula)* the light issues from the under surface of the three last abdominal rings: it is most brilliant in the female, and exists in a feeble degree in the eggs, larvæ, and chrysalis. In some of the *Fire-flies* of warm countries the light is emitted from two very brilliants points on the front of the thorax; and in the splendid *Fulgora*, of which different species constitute the gigantic *Lantern-flies* of South America, China, and the East Indies, the luminous part is a bladder-like protuberance arising from the anterior portion of the head. The conditions under which their phosphorescence is displayed resemble those which have been mentioned in the last section. It appears to be occasioned by the secretion of some product possessing a luminous property, which is dependent for its continuance upon the life and health of the animal; it is stimulated by anything which excites the vital functions of the individual, and is stated by Treviranus to be particularly influenced by the activity of the respiratory process.

476. Phosphorescence is a rare phenomenon among aerial animals of the higher classes. An emission of light has been seen from the egg of the grey lizard; and it has been stated that a species of frog or toad

inhabiting Surinam is luminous. Of its particular objects in the Animal economy, little is known, and much has been conjectured. It is generally imagined, that it is destined to enable the sexes of the nocturnal animals (especially insects) to seek each other for the perpetuation of the race; and this hypothesis would seem to derive support from the fact that the light is generally most brilliant at the season of the exercise of the reproductive functions, and at that period exists in some of the species (such as the earthworm) which do not manifest it at any other. Moreover it is well known that the male glow-worm, which ranges the air (whilst the female, being destitute of wings, is confined to the earth), is attracted by any luminous object; so that the poetical language of Dumeril, who regards the phosphorescence of the female as "the lamp of love—the pharos—the telegraph of the night, which scintillates and marks in the silence of darkness the spot appointed for the lovers' rendezvous," would not seem so incorrect as the ideas of Poets on subjects of Natural History usually are. It may be objected on the other hand, that there are many moths and beetles, which have a similar tendency to fly towards the light, and among which no phosphorescence is exhibited. Some of these, however, are faintly luminous; and it would not seem improbable that the insects which are attracted by flame, and thus show that they are seeking for objects which emit light, may be cognisant of more feeble degrees of its emission, than our eyes can appreciate. Still it must be remembered that many animals are phosphorescent which have no occasion to seek each other with this object; thus, *Sponges*, *Sertulariæ*, *Pennatulæ*, and other Polypifera exhibit some degree of luminosity, as well as those already mentioned. It is not impossible that the property may be conferred upon them (like the stinging power possessed by some) as a means of self-defence, in the deficiency of active powers of locomotion, or of dense external covering.

477. An evolution of light during the incipient decay of dead animal matter, is by no means of uncommon occurrence. It has been most frequently observed to proceed from the bodies of Fishes, Mollusca, Medusæ, and other marine tribes; but it has been seen also to be evolved from the surface of terrestrial animals, and even of man. This phosphorescence ceases immediately on the commencement of fetid putrefaction; and would appear to proceed from the formation of luminous matter during an early stage of decomposition, by some of the primary changes in the combination of the organic elements which immediately succeed death.*

* May not this fact have some connexion with the extraordinary phenomenon of *spontaneous combustion*? There are some well authenticated instances in which the combustion has commenced without the proximity of an ignited body; and the author has seen a remarkable case, drawn up under the hand of the subject of it (a highly respectable clergyman) and shown him by Dr. M. Barry, in which a troublesome sore, occasioned by the combustion of

Evolution of Heat.—General Considerations.

478. As it is a part of the peculiar character of living organised beings to resist the influence of a variety of external agents, provided that these be not in such violent operation as actually to check the vital processes, it is obviously necessary that they should be endowed with the means of preserving that uniform temperature which is most favorable to the performance of their various actions. We have already considered the means by which the influence of an excessive degree of external heat is resisted (CHAP. X.); we have now to enquire into those by which a sufficient degree of warmth is preserved in the living system, when there is an absence of it in the surrounding medium. It is well known that almost all chemical changes are attended with some disturbance of the temperature of the agents concerned; and it may not unreasonably be surmised that of those which are so constantly occurring in the living system some may be connected with the disengagement of the heat peculiar to it. Much uncertainty still prevails on this subject; but there can be little doubt that a large proportion of the caloric liberated by organised beings is generated by the combination of atmospheric oxygen with the carbon furnished by them, to form the carbonic acid which they are constantly excreting, since we find these two changes everywhere bearing a close relation with each other. The particular connexion between them will now be considered in some detail.

Evolution of Heat in Vegetables.

479. Much dispute has occurred at different periods as to whether Plants could be considered as having a *proper heat* or not; and this has resulted from the limited view which has been taken of the processes of the Vegetable Economy. Although the excretion of carbonic acid is constantly going on, under the conditions formerly described, it usually takes place so slowly, and from a surface so openly exposed to the atmosphere, that it could scarcely be expected that there should be any sensible elevation of the temperature of the part from this source; and, as the circulation of elaborated sap is not performed with sufficient rapidity to convey caloric set free in one part to distant portions of the system, a *general* maintenance of vital warmth would be still less anticipated. In plants of small or moderate size, accordingly, the temperature is found to be depressed with that of the atmosphere; but the interior of large trunks seems to maintain a more uniform degree, being colder than the atmosphere in summer and warmer in winter. This fact may be

phosphorus on the hand, twice at distant intervals emitted a flame which burned the surrounding parts. It was particularly stated that ignition could not have been effected by any neighbouring flame; and that the combustion could not be due to any particles of phosphorus remaining in the wound.

accounted for on two different grounds. The slow conducting power of the wood, which is much less transversely to the direction of its fibre than with it, would prevent the interior of a large trunk from being rapidly affected by changes in the heat of the external air; and accordingly, it is found that the larger the trunk on which the observation is made, the greater is the difference. Again, some motion of the sap takes place even in winter; and as the earth, at a few feet below the surface, preserves a very uniform temperature, it is not improbable that the transmission of fluid derived from it through the stem, may have an influence on the state of the latter;—a supposition which is countenanced by the fact, that the temperature of the interior of a large trunk and that of the soil four feet below the surface (which may be regarded as the medium depth of roots) bear a very close correspondence. It is reasonable to suppose that both these causes may be in operation.

480. It is, however, when the processes of vegetation give rise to an extraordinary liberation of carbonic acid, that the evolution of heat becomes manifest. This is the case during germination, when the elevation of temperature, scarcely manifested by a single seed, becomes evident if a number are brought together, as in the process of malting, in which the thermometer has been seen to rise to 110°. The same may be said of the other period of vegetable growth in which the function of respiration is carried on to a remarkable extent—that of flowering. From the large surface exposed it is evident that, in by far the greater number of of instances, the heat will be carried off by the atmosphere the instant it is developed; nevertheless the flowers of a Cistus showed a temperature of 79° whilst the air was at 76°, and those of a Geranium 87° when the air was at 81°. It is in plants of the Arum tribe, however, where flowers are collected in great numbers within cases which act as non-conductors, that the elevation of temperature becomes most appreciable; and it bears a definite relation with the quantity of oxygen converted into carbonic acid (§ 381). Thus, a thermometer placed in the centre of five spadixes of the *Arum Cordifolium* has been seen to rise to 111°, and in the centre of twelve to 121°—while the temperature of the external air was only 66°; but the heat was wholly destroyed by preventing the spadix from coming in contact with the air. The truth of statements of this sort, which have been questioned by many physiologists, has recently been placed beyond all doubt by the observations of Adolphe Brongniart.* He found that, at the first opening of the spathe of *Colocasia odora*, the temperature of the spadix was 8.1° above that of the surrounding air; that this increased during the next day to 18°; and, during the emission of the pollen on the three succeeding days, to 20°; after which it began to diminish with the fading of the flower.

* Nouv. Ann. du Musée, tom. III.

Evolution of Heat in Animals.

481. Although we find in the Animal kingdom many instances in which the capability of maintaining an elevated and uniform temperature is exhibited in a degree to which nothing comparable exists in plants, yet this is by no means a constant function of animal any more than of vegetable organisms. It would indeed appear that, as far as the functions of organic life are concerned, the regular performance of them is quite compatible (under certain limits) with a degree of heat almost entirely dependent upon that of the external medium. Accordingly we find in the lower tribes of Animals, in which the power of locomotion is but feeble, and the supply of the wants of the system not immediately dependent upon it, that very little more heat is generated than in plants. But wherever a high degree of muscular energy is required, in connexion with a general activity of the functions of the nervous system, the evolution of caloric to a remarkable extent is provided for in the nutritive processes. We may regard it, therefore, as in *its degree* essentially connected with the development of the animal powers relatively to the system of organic life, although really *dependent*, as it would appear, upon the changes occurring in the latter. It is worthy of notice that, although the temperature of the various parts of the animal body is usually much more uniform than that of the different organs in vegetables (owing to the comparative rapidity with which the general circulation of the former diffuses the heat evolved in any one part, and thus tends to equalize the whole), wherever processes are going on which call the nutritive functions into extraordinary activity, *there* a corresponding elevation of temperature occurs. Thus, a slightly increased evolution of heat from the stomach has been observed during the determination of blood to its capillaries, which takes place during digestion; the same is observable in the reproductive organs of those animals in which the aptitude for the function is periodic only; the temperature of a muscle (as ascertained by MM. Becquerel and Breschet) rises a degree or more during its contraction; and that of the uterus during the parturient efforts has been stated (by Dr. Granville) to be occasionally 22° above the natural standard, and to vary with the force of its contractions.

482. Our knowledge of the heat evolved by the lower INVERTEBRATA is very limited, and is principally derived from the experiments of John Hunter. He found that a thermometer introduced in the midst of several *Earthworms*, stood at $58\frac{1}{2}$° when the temperature of the external air was 57°; and in another instance, when the atmosphere was at 55° the worms were at 57°. The amount of heat manifested by *Leeches* appeared to be nearly the same, viz. from one to two degrees above that of the atmosphere. Of the MOLLUSCA, nearly the same may be said. Hunter found that black slugs *(Limax ater)* exhibited a temperature of $55\frac{1}{4}$

when that of the atmosphere was 54°; and the garden snail *(Helix pomatia)* has been observed by others to evolve about the same amount of heat. Further experiments, however, are desirable for the purpose of ascertaining whether the power of generating caloric varies in such animals with different degrees of external temperature; or whether the heat of their bodies always bears the same close relation with that of the medium in which they exist. The only information on this subject which we possess is derived from the experiments of Hunter. He put several leeches into a bottle which was immersed in a freezing mixture, and, the ball of the thermometer being placed in the midst of them, the quicksilver sunk to 31°; by continuing the immersion for a sufficient length of time to destroy life, the quicksilver rose to 32°, and then the leeches froze. A similar result was obtained with a snail. It would appear therefore, that these animals have the power of resisting, *for a time*, the physical effects of cold; but how far this resistance is due to the power of generating heat, or to the causes arising from their structure (as in vegetables § 173) cannot be determined without further enquiries.

483. In many Vertebrated animals, the heat of the body is almost equally dependent upon that of the surrounding medium. Thus, FISHES in general do not seem capable of maintaining a temperature more than two or three degrees higher than that of the water in which they live. There are, however, some remarkable exceptions; for Dr. J. Davy found that certain salt-water fishes, as the bonito and thunny, whose gills are supplied with nerves of unusual magnitude, and which have also a very powerful heart, and a quantity of red blood sufficient to give the muscles a dark red colour, manifest a degree of temperature much higher than that of the white fishes of fresh-water on which Hunter experimented. Thus, Dr. D. observed in the bonito a temperature of 99° whilst that of the sea was but 80½°. Although the conditions of existence in Vertebrata, in which the animal powers are developed to their greatest extent, might have seemed to require a greater power of generating heat than Fishes usually possess, it is to be remembered that this class is less liable to suffer from alternations of temperature connected with the seasons than those which inhabit the air. In climates subject to the greatest atmospheric changes, the heat of the sea is comparatively uniform through the year, and that of deep lakes and rivers is but little altered. Many have the power of migrating from situations where they might otherwise suffer from cold, into deep waters; and it is an unquestionable fact that the species which are confined to shallow lakes and ponds, and which are thus liable to be frozen during the winter, are frequently endowed with sufficient tenacity of life to enable them to recover after a process which is fatal to animals much lower in the scale.

484. In REPTILES the power of maintaining an uniform temperature is somewhat greater. We not only observe an increased capability of

generating caloric, but also a peculiar means of resisting the influence of a too elevated degree of external heat (§ 437). In all cases, however, the temperature of their bodies is greatly dependent upon that of the medium which they inhabit; but in proportion to the depression of the latter, do they seem endowed with the power of maintaining their own above it. Thus, when the air was at 68°, a *Proteus* manifested the same degree of heat; but when the air was lowered to 55°, the temperature of the animal was 65°. In the same manner it appeared that the edible frog *(Rana esculenta)* possessed a temperature of 72½° when examined in an atmosphere of 68°; and that in water of 21° the animal maintained a heat of 37½°. The *Chelonia* do not seem endowed with the power of evolving heat to the same degree with the *Saurian* and *Ophidian* reptiles. In some of the more agile of the Lizard tribes, the high temperature of 86° has been noticed, when that of the external air was but 71°. In all experiments on the influence of *change* of temperature on such animals, it is necessary to guard against the fallacy arising from the slowness (resulting from their non-conducting power) with which their bodies acquire the altered heat of the medium, whether it be increased or diminished. By attending to this precaution it has been shown that many of the statements which have been made regarding their power of modifying their temperature are liable to exception; but it cannot be questioned that Reptiles have some capability of generating heat, which is called into action in resisting the depressing influence of cold. This is unequivocally proved by the fact that frogs will remain alive in water which is frozen around them (even when the thermometer has fallen to 9°), the water in contact with the body remaining fluid and the temperature of the body being 33°.

485. The classes of animals which are especially endowed with the property of producing and maintaining heat are Insects, Birds and Mammalia. The temperature of INSECTS has been very ably investigated by Mr. Newport; and from his recent communication on the subject to the Royal Society* the following facts are selected. In the *Larva* condition the temperature of the animal corresponds much more closely with that of the atmosphere than in the perfect state; thus, the larva of the higher species of *Hymenoptera*, (Humble-bees, &c.) is usually from 2° to 4° above the surrounding medium, whilst the perfect Insect has a range of from 3° to 10° or even more; and the Caterpillar of the *Lepidoptera* (Butterfly tribe) is seldom more than from ½° to 2° warmer than the atmosphere (the amount varying in close relation with the activity of the individual); whilst the perfect insect is, when much excited, 5° or 9° above it. It is probable that in those tribes in which no complete metamorphosis exists, but in which the difference between the development of the larva and that of the perfect insect is but trifling, there is not the

* Philos. Trans. 1837.

same variation with regard to the production of heat. The *Pupa* state being, in all insects which undergo a complete metamorphosis, a condition of absolute rest, the temperature of the individual is in general lower than at any previous or subsequent period of its existence; and is it only equal to, or at most very little above, that of the surrounding medium. But in those species which, not undergoing a complete metamorphosis, continue active during the whole of life, this diminution of the power of maintaining heat probably does not occur. Within a short period after the first change, however, the Pupa often retains some of the characteristics of the larva state, and exhibits a temperature somewhat elevated; and if at any time excited to motion, a slight degree of heat is manifested. The pupa appears to follow variations in atmospheric temperature more rapidly than the larva; and as an elevation of temperature becomes necessary towards the epoch when the final metamorphosis is to take place, means are provided for it. In the Lepidoptera the Chrysalis has itself the power of generating heat at the period when its energies are aroused, and it is about to burst forth from its silky envelope; whilst in the Hymenoptera it is most curious to observe an artificial warmth communicated to the pupæ by an increased evolution of heat from the bodies of the perfect insects which crowd over their cells (§ 488).

486. The increase in the power of generating heat which is characteristic of the perfect Insect is not manifested immediately on its emersion from the pupa state; in fact at that period, when the body is soft and delicate, and the unexpanded wings hang uselessly from its sides, it parts with its heat with great rapidity. It is not until its active respiratory movements have commenced, and the whole system has been stimulated by the exercise of its locomotive powers, that the evolution of heat takes place to any remarkable extent; and whether these processes be delayed or hastened by the influence of external circumstances, the elevation of the temperature of the individual is still proportional to them. Thus, a specimen of the *Sphinx ligustri* which had only left the pupa state about an hour and a quarter, had a temperature of but 4° above the atmosphere; whilst, at the expiration of two hours and a quarter, when it had become strong and had just taken its first flight, it had a temperature of 5·2°; and another specimen which had been longer exerting itself in rapid flight, was as much as 9° warmer than the surrounding air. In the states of abstinence, inactivity, sleep, and hybernation, the evolution of heat is checked; and the temperature of the perfect insect may fall very nearly to that of the atmosphere. By inordinate excitement, on the other hand, a very rapid evolution of heat may be produced. Thus, a single individual of *Bombus terrestris* (Humble-bee) enclosed in a phial of the capacity of three cubic inches, had its temperature gradually raised, by violent excitement, from that of rest (two or three degrees above that of the atmosphere) to 9° above that of the external air, and had communi-

cated to the air within the phial as much as 4° of heat within five minutes. In an experiment upon another species, *Bombus Jonella*, the temperature of the air within the phial was raised by the motion of the insect during six or eight minutes as much as 5·8° above that of the atmosphere; but when the bulb was held near enough to the insect to touch the tips of its wings, the mercury sunk 2·2°. This observation, which was repeated several times with the same results, shows that the vibration of the wings tends to cool the body of the insect during its flight.

487. Of the temperature of different tribes of perfect Insects, Mr. Newport remarks, " Our previous observations lead us to anticipate the fact, that the volant insects in their perfect state have the highest temperature, while on pursuing the enquiry it is found that those species which have the lowest temperature are located on the earth. Among the volant insects, those Hymenopterous and Lepidopterous species have the highest temperature, which pass nearly the whole of their active condition on the wing in the open atmosphere; either busily engaged in the face of day, despoiling the blossoms of their honied treasures, or flitting wantonly from flower to flower, and breathing the largest amount of atmospheric influence. Of these the Hive-bee with its long train of near and distant affinities, and the elegant and sportive Butterflies have the highest. Next to these are probably their predatory enemies the Hornets and Wasps, and others of the same order; and lastly a tribe of insects which have always attracted attention, and in general are located upon the ground, but sometimes enjoy the volant condition—the Ants, the temperature of whose dwellings has been found to be considerably above that of the atmosphere. Next below the diurnal insects, are the crepuscular, the highest of which are the Sphinges and Moths, and almost equal with them are the *Melolonthæ* (Chaffer tribe)." In some of the *Coleoptera* (Beetle tribe) the amount of heat is found to approach very nearly to that in *Hymenoptera;* in both of these tribes the organs of respiration are of large extent, and the quantity and activity of aeration considerable. On the other hand, the inferior temperature of crepuscular Insects to that of diurnal species of the same orders is associated with a lower degree of respiration. Nearly all the Hymenoptera are diurnal, and bear the privation of atmospheric air with greater difficulty than many other tribes. Further it would appear that some of the volant Coleoptera have, even in a quiescent state, a higher temperature than some of the terrestrial Coleoptera in a state of moderate activity, the difference being much increased in the active condition of the former.

488. It is among the Insects which live in societies, however (all of them belonging to the order of Hymenoptera) that the greatest evolution of heat is manifested. Mr. Newport's observations were made principally upon the *Bombus terrestris* (Humble bee) and *Apis Mellifica* (Hive bee).

A single individual of the former species frequently, when moderately excited, has a temperature 9° above that of the atmosphere; but that of the nest, examined in its natural situation, was from 14° to 16° above that of the atmosphere, and from 17° to 19° above that of the chalk bank in which it was formed. But the generation of heat is increased to a most extraordinary degree at the period when the nymphs (pupæ) are about to come forth from their cells, and consequently require a higher temperature. This is furnished by the individuals denominated by Huber *Nurse Bees*, and of these Mr. Newport gives the following interesting account:—"These individuals are chiefly young female bees; and, at the period of hatching of nymphs, they seem to be occupied almost solely in increasing the heat of the nest, and communicating warmth to the cells by crowding upon them and clinging to them very closely, during which time they respire very rapidly, and evidently are much excited. These bees begin to crowd upon the cells of the nymphs, about ten or twelve hours before the nymph makes its appearance as a perfect bee. The incubation during this period is very assiduously persevered in by the nurse-bee, who scarcely leaves the cell for a single minute; when one bee has left, another in general takes its place: previously to this period the incubation on the cell is performed only occasionally, but becomes more constantly attended to nearer the hour of the development. The manner in which the nurse-bee performs its office is by fixing itself upon the cell of the nymph, and beginning to respire very gradually; in a short time its respiration becomes more and more frequent until it sometimes respires at the rate of 130 or 140 per minute." In one instance the thermometer introduced among seven nursing-bees stood at 92½°, whilst the temperature of the external air was but 70°. The greatest amount of heat is generated by the nurse-bees just before the young bees are liberated from the combs, at which period they require the highest temperature. It is just after its emersion that the young insect is most susceptible of cold; it is then exceedingly sleek, soft, and covered with moisture; it perspires profusely, and is highly sensitive of the slightest current of air. It crowds eagerly among the combs and among the other bees, and everywhere that warmth is to be obtained. It is not until after some hours that it becomes independent of external warmth. It is interesting to remark that these bees do not incubate on cells that contain only larvæ; the temperature of the atmosphere of the nest being sufficiently high for them in that condition and to perfect their change into the pupa state.

489. Similar observations have been made by Mr. Newport upon the temperature of the Hive-bees; and he has shown the fallacy of the statements of other experimenters, as to the degree of heat maintained by them during the winter, to arise from the rapidity with which, when aroused, they can generate caloric. The temperature of individual bees in a state of moderate excitement, is usually from 10° to 15° above that

of the atmosphere; but it is greatly increased about the swarming season when incubation of the pupæ is going on, and also when clusters are formed round the entrance of the hive. At such times Mr. N. has seen the thermometer raised as high as 96° or 98° when the range of atmospheric temperature was only between 56° and 58°. The *mean* temperature of a hive during May was 90°, that of the atmosphere being 60°; whilst, in September, the mean of the atmosphere being also 60°, that of the hive was only 66½°. During the winter, it now appears that bees, like other insects, exist in a state of hybernation; though their torpidity is never too profound for them not to be aroused by moderate excitement. The temperature of the hive is usually from 5° to 20° above that of the atmosphere; but it is sometimes depressed even below the freezing point. It is when artificially excited in a low temperature that their power of generating Caloric becomes most evident. Mr. N. mentions one instance in which the temperature of a hive, of which the inmates were aroused by tapping on its exterior, was raised to 102°, a thermometer in the air standing at 34½°, and the temperature of a similar hive which had not been disturbed being only 48½°.

490. All insects appear to have, in greater or less degree, the power of moderating the heat of the body when too great, by transpiration from its surface (§ 436). But Hive-bees have a peculiar means of depressing the heat of their residence, when excessive, by a process of *ventilation*. A number of them take their stand in the neighbourhood of the entrance, and, by the rapid agitation of their wings, drive a current of cool air through the hive. This may be witnessed not only in summer, when the temperature of the atmosphere is high, but on occasions when, the external air being cool, the hive has been heated by artificial excitement. In regard to the degree of heat they are capable of generating, therefore, it appears that Insects may be ranked between cold and warm-blooded animals. Like the former, they are much influenced by external temperature; although the higher species are, when in a state of moderate exercise, relatively warmer than the least cold-blooded among the Reptiles. The degree of heat they are *occasionally* capable of evolving is nearly equal to that generated by Mammalia; but this is only required for the performance of particular functions, and, if constantly maintained in Insects, would have occasioned an unnecessary activity in the processes on which it is immediately dependent, and, by consequence, in the whole of the nutritive system. In Birds and Mammalia, however,—where, from the high development of the animal powers, the *constant* maintenance of an elevated temperature is necessary,—all the functions are adapted to its support; and in them we no longer find any dependence upon the state of the external medium, the calorific and frigorific processes being so delicately adjusted, as to render the heat of the system extremely uniform.

491. The temperature of BIRDS is, almost without exception, higher than that of the Mammalia, varying from 100° to $111\frac{1}{4}$°. The first is that of the *gull*, the last that of the *swallow*. In general, the same statement may be applied to birds, as has been made with respect to Insects, that the temperature is greatest in the species of most rapid and powerful flight, (which in both cases are those of medium size), and least in those which principally inhabit the earth, as the Fowl tribe. Birds that inhabit the waters have a special provision for retaining, within their bodies, the heat which would otherwise be too rapidly conducted away, in the thick and soft down with which they are clothed, and which is rendered impervious to fluid by the oily secretion applied with the bill. The temperature of the MAMMALIA seems to range from about 96° to 104°; but more accurate observations are still required for the sake of comparison. That of the Cetacea (Whale tribe) does not seem to be inferior to that of other orders; and, to retain it within the body, a thick layer of fat is disposed beneath the skin, by which the conducting power of the medium they inhabit is prevented from operating too energetically and injuriously. The heat of different parts of the body varies a good deal according to the degree of surface exposed; and it seems greater among the viscera, than in any situation ever exposed to the air. Thus, the temperature of the human body is usually stated at 98°, from the height of thermometers placed in the mouth, armpits, &c.; but that of the stomach, according to Dr. Beaumont, is generally 100°; and that of the blood from $100\frac{1}{2}$° to $101\frac{1}{2}$°.

492. In Birds, as in Mammalia, it is found that young animals have less power of maintaining an independent heat than adults. The embryo, whether in the egg or within the body of its parent, is dependent upon external sources for the heat necessary to its full development. The contents of the egg when lying under the body of its parent are so situated that the germ-spot (§ 535) is brought in closest proximity with the source of warmth. Eggs may, however, be artificially incubated, a practice which is carried to great extent in Egypt; and in tropical climates the heat of the sun is in some instances sufficient. Thus, the Ostrich is said to leave her eggs to be hatched by the sun's rays alone, when she breeds in the neighbourhood of the Equator; and to sit upon them if inhabiting a more variable climate. It was observed by Mr. Knight that a fly-catcher, which built for several successive years in one of his stoves, quitted its eggs whenever the thermometer was above 71° or 72°, and resumed her place upon the nest when the thermometer sunk again.* The incubation of bees evidently bears a close analogy with that of Birds; since, upon the principles already stated (§ 80), the larva and pupa states of the Insect are but peculiar conditions of the embryo; and it is not until the final metamorphosis that the true characters of the class are

* Jesse's Gleanings, 1838, vol. i. p. 112.

manifested. Just as in Insects, also, the young of the warm-blooded Vertebrata have not, until some time after birth, the power of maintaining an independent temperature. Thus, Edwards found that young sparrows, a week after they are hatched, have, while in the nest, a temperature of from 95° to 97°; but when they are taken from the nest, their temperature falls in one hour to 66½°, the temperature of the atmosphere being at the same time 62½°;—and this rapid cooling was shown by parallel experiments not to be owing to the want of feathers. This fact, however, is not applicable to all birds; for there are some which can maintain an elevated temperature from the time they are hatched, unless the air be cold. They come into the world in a more advanced state than other species, being able to eat and run from the first. Among the Mammalia there is considerable difference in the degree of development which the young have attained at the time of their quitting the uterus of the parent. Thus, the fœtus of the *Marsupialia* is transferred at a very early period to the pouch where it adheres to the nipple; and it is for a long time as much dependent upon its parent for warmth as if it remained within the uterus. The young of dogs, cats, rabbits, &c. which are born blind, can only be regarded as having attained the same degree of development with those which, in other species, continue longer in the interior of the parent; and accordingly they very soon part with their warmth to the atmosphere, if it is not maintained by contact with their nurse. Thus, the temperature of new-born puppies removed from the mother, will rapidly sink to within 2 or 3 degrees of that of the air; but, as among birds, there are some species which are capable from the first of preserving their standard heat if not exposed to too low a medium. Young Guinea-pigs, for example, are able from birth to walk and run, and to take the same food with the mother; they seem to have the power of maintaining a steady temperature when the season is not severe, but have not the same capability with the adult of resisting cold.

493. The extraordinary phenomena of hybernation, a state in which warm-blooded animals are reduced to the condition of those of least independent temperature, has been already described (§ 156); it need only here be added that they still preserve the *capability* of evolving heat, when stimulus of any kind arouses the animal functions, and gives a temporary excitement to those of organic life.

494. We have now to enquire what are the *conditions* of the evolution of heat in the animal economy. That many of the nutritive processes are connected with it can scarcely be doubted; but it seems peculiarly to depend upon those changes in which the function of Respiration is concerned—viz. the extrication of carbon from the system, in combination with oxygen derived from the atmosphere. Wherever the aeration of the blood is extensively and actively carried on, there is a proportionate elevation of temperature. And, on the other hand, wherever the respiration

is naturally feeble, or the aeration of the blood is checked by disease or accidental obstruction, the temperature of the body falls. Thus, in spasmodic asthma, the temperature of the human body during a paroxysm has been found as low as 82°; in the Asiatic Cholera, a thermometer placed in the mouth has indicated but 77°; and in *Cyanosis* (or *blue disease*, arising from malformation of the heart impeding perfect arterialisation, § 329), the same low temperature has been observed. Again, whenever the temperature of an animal is, by any extraordinary stimulus, quickly raised above that which it was previously maintaining, it is always in connexion with increased activity of the respiratory movements, and increased consumption of oxygen. Thus, during the incubation of bees, the insect, by accelerating its respiration, causes the evolution of heat and the consumption of oxygen to take place at least *twenty* times as rapidly as when in a state of repose. There is a remarkable similarity between the occasional activity of the respiratory function in Insects, and the constant energy with which it is performed in Birds—the Insects of the vertebrated classes. We have seen that in the former the circulation is very feeble, whilst the respiratory tubes are prolonged into every part of the system; so that when the air is rapidly driven through them by movements adapted for the purpose, the aeration of the blood is very completely effected. In Birds we observe a similar tendency to diffusion of the respiratory apparatus through the system; but the energy of circulation renders this less necessary than in Insects, and the aeration of the blood is principally effected by its transmission through those organs which in the Mammalia are alone adapted to it. The mode and degree in which the evolution of heat is connected with the aeration of the blood, has long been a fruitful topic of discussion amongst physiologists; we shall only state therefore what appear to be legitimate inferences from facts. It has been seen that arterial blood contains oxygen in a free state, or at least in such loose combination that it is separated with facility. During its passage through the capillaries this oxygen is exchanged for carbonic acid which replaces it in venous blood. The carbon which is thus received into the blood is evidently disengaged from the tissues during the process of nutrition; and its union with oxygen, which is the means of its disengagement, must be accompanied, as in the processes of inorganic chemistry, with a liberation of caloric. This will in general be nearly uniform throughout the system; but there are many cases in which increased action is going on, either as a natural condition or as a diseased state; and a higher local temperature is thus produced. This would seem to be in some degree connected with the influence of the nervous system; but it may be regarded as probable that the evolution of caloric is not dependent upon nervous action in any other way than through those organic processes which stand in relation to both.

495. The results obtained by various experimenters would appear to

indicate, that some other organic processes besides those connected with the excretion of carbon through the lungs, must contribute to the maintenance of the heat of warm-blooded animals; since the amount of caloric given out during a certain time to the surrounding medium, is greater than that which would be produced by the combustion of a quantity of carbon equivalent to that which has been expired during the same period. What these processes are is a matter upon which at present we can only speculate; and there are so few data upon which reliance can be placed that it is perhaps better to abstain from erecting hypotheses upon them. It has been seen that the evolution of heat in plants appears solely connected with the formation of carbonic acid; and it is a fact of no little interest that, after the bond of union between the animal functions has been dissolved by death, but some organic life is still retained by the individual parts, an elevation of temperature will occasionally take place, and the glow of health will return to the skin. This has been frequently witnessed in cases of death from various forms of asphyxia, and from cholera; it would appear to be due to the aeration of the blood contained in the capillaries of the skin, by the influence of the atmosphere upon them; and the same change will probably be effected by the entrance of air into the lungs, when there has been previously any mechanical impediment to its meeting in those organs with the circulating fluid. When animal life has been suddenly and completely destroyed by injuries of the nervous system, the action of the heart frequently continues for some time, if means are provided for the aeration of the blood. This may be accomplished by an artificial respiration, which if carefully performed is found to retard in great degree the natural cooling of the body; in the experiments which have had a contrary result, the insufflation of the lungs was probably repeated too frequently and violently, so as to hasten the refrigeration by the quantity of cold air thus introduced into the system. It has been also shown by the experiments of Dr. Southwood Smith,* that though a moderate inspiration favours the passage of the blood through the lungs, great distention of their cavity with air, checks almost entirely the circulation of fluid through them; and this cause also no doubt had its operation in producing the effects, which have led to the opinion of some physiologists that animal heat is immediately produced by nervous agency,—an opinion quite inconsistent, as we have seen, with the facts supplied by a comprehensive survey of organised nature.

Evolution of Electricity.—General Considerations.

496. It has been mentioned (§ 151) that Electricity, like Gravitation, is probably to be regarded as a property common to all forms of matter, and capable of being manifested whenever the requisite conditions are fulfilled. Its development takes place in the inorganic world under a

* Philosophy of Health, Vol. II. p. 75, &c.

great variety of circumstances; and there is scarcely a chemical or physical change of any kind, which is not accompanied by some disturbance of its equilibrium, although it may be too slight to be recognised without very refined means of detecting it. The *contact* of two different substances is by some regarded as of itself capable of producing electric excitement; and, if we prefer to think with other philosophers that it is by the chemical action or the change of temperature thus produced that the disturbance of the equilibrium is really occasioned, still the constant occurrence of such changes cannot be viewed without interest in connexion with the phenomena of life. Not only inorganic bodies, such as metals, but organised tissues and fluids will thus manifest electricity. A weak galvanic pile has been formed with alternate layers of muscle and nerve; and even with organic fluids of different kinds, when separated by disks of paper. White of egg, for instance, is positive to bullocks' blood; blood is positive to starch; starch to gum; and gum to tragacanth mucus; linseed oil, again, is positive to wax; and yeast to sugar.—But there are other sources of the development of electricity which seem to bear a still closer relation with the processes constantly taking place in the living body. Thus, change of temperature disturbs the the equilibrium of a single bar of metal, if two parts be unequally heated: and the disturbance is greater if two metals be in contact. Change of form, again, is another source of electricity, which appears to be developed during the processes of liquefaction and solidification, and the formation and condensation of vapour. Thus, if sulphur be melted in a glass vessel, and the cake be removed after cooling, the sulphur is found to be negative and the glass positive; and the evaporation of pure water from a platinum surface is attended with distinct development of electricity. If, however, the change of form be accompanied with any chemical decomposition, the manifestation of electricity becomes much more decisive; as when saline solutions are evaporated, the water of which is consequently separated from the salt to which it was previously united. Since all the water on the surface of the globe has some saline impregnation, there can be little doubt that its constant evaporation is a fertile source of atmospheric electricity.

497. Perhaps the most frequent and powerful source of electrical disturbance is chemical action. It seems to be now generally admitted from the experiments of Faraday, Becquerel, De la Rive, &c., that, in every instance of chemical union or decomposition, some excitement of this agent takes place. Thus, in all combustion of inflammable material, whether pure carbon, or hydrogen, alcohol, oil, &c., the gas or vapour arising from it is positive, whilst the combustible is negative. The manifestation of their respective conditions can only be obtained, however, by immediately separating them; for, if the carbonic acid arising from the combustion of charcoal be allowed to flow over the surface of the mass, the equilibrium is restored. This fact explains the absence of electric

disturbance in ordinary chemical operations, where new combinations are formed by the union of the elements or by the decomposition of others previously existing; for, if the substances thus produced remain in contact, the equilibrium which was disturbed by their change is immediately restored.* There can be little doubt that *capillarity* has a very important power in modifying the chemical affinities of various bodies for each other. Thus, spongy platinum will cause the union of oxygen and hydrogen at ordinary temperatures, without itself undergoing any change; and porcelain biscuit heated to 300° has the same effect. Again, charcoal, especially when newly burned, absorbs many times its own bulk of different gases, especially such as may be artificially condensed into a fluid form; and it appears to be from the latent caloric thus evolved that its spontaneous ignition sometimes occurs. The phenomena of endosmose (§ 244) also seem connected with electric disturbance, though whether in the relation of cause or effect is hardly yet ascertained.

498. The late researches of Dr. Faraday appear to have fully proved the identity of chemical affinity with electrical attraction; and it is not surprising, therefore, that all chemical changes should be attended with a development of electricity. If, as has been maintained (§ 162), the changes that constitute the growth of organised systems, of their alimentary materials into products adapted to the nutrition of their structures, are *immediately* controlled by laws similar to those which govern the combinations of inorganic matter, it would naturally be expected that electricity should be generated by them: and this agent may sometimes be required for the performance of other processes in the individual economy, and may sometimes contribute to those more evident and striking phenomena, the consideration of which is included under the science of Meteorology. If the physical sources of electric excitation be kept in view, no great difficulty will be felt in accounting generally for those peculiar instances in which an extraordinary manifestation of it occurs in the animal system (§ 505), although we may not be able to apply our explanations to their details.

Electricity in Vegetables.

499. That the ordinary processes of vegetable growth are attended with a manifestation of Electricity, has been proved by the experiments of

* Acting upon this principle, M. Becquerel has succeeded in forming an energetic galvanic apparatus in a very simple manner. If a syphon be filled with fine sand, and into one leg be poured an acid, and into the other an alkaline solution, chemical union of these agents will of course take place at the depending curve. At this point, however, an orifice is made, and plugged with a few filaments of asbestos, which draw off the compound solution as fast as it is formed. Wires placed in the two legs indicate strongly-opposed electrical states; and the voltaic current thus produced continues until all the original solutions have united. It is impossible to contemplate this result without acknowledging the influence that the mode in which the elements are brought together must have upon their actions; in this case it is the slow union resulting from their capillary division, which enables the conditions requisite for the manifestation of electricity to be complied with.

Pouillet.* The disengagement of vapour from the surface of the leaves would alone be sufficient to produce it, as the fluid from which it is given off is always charged with saline and other ingredients; and the gaseous changes which are effected by the leaves upon the oxygen and carbonic acid of the atmosphere may be regarded as other sources of its development. Although it is not improbable that the electric state of plants will vary according to the nature of the changes which they undergo in relation to the atmosphere, yet their usual condition is negative; and a very ingenious theory has been erected by Dr. Graves upon this fact, to account for the violence of meteorological phenomena in tropical islands. The evaporation taking place from the surface of the sea, must tend to render the superincumbent atmosphere positively electrical; and that, too, with the most intensity during the day, at the very time when the agency of terrestrial vegetation is rendering the air over the land negatively electrical. "How wonderful," he continues, "are the operations of nature! The peaceful and silent growth of a vegetation whose splendour fascinates the eye, developes an agency which, opposed to that produced by a rapid but unobserved evaporation from the surface of the surrounding ocean, tends to load the atmosphere with conflicting elements, from the depth of whose strife issues thunder proclaiming the approach of the hurricane and tornado."

500. During the various processes of decomposition and recomposition which take place in the assimilation of the Vegetable juices, we should expect that electric equilibrium would be sometimes disturbed, sometimes restored. Of this, the following facts, amongst others, appear to be sufficient evidence. If a wire be placed in apposition with the bark of a growing plant, and another be passed into the pith, contrary electrical states are indicated, when they are applied to an electrometer. If platinum wires be passed into the two extremities of a fruit, they also will be found to present opposite conditions. In some fruits, as the apple or pear, the stalk is negative, the eye positive; whilst in such as the peach or apricot, a contrary state exists. If a prune be divided equatorially, and the juice be squeezed from its two halves into separate vessels, its portions will in like manner indicate opposite electrical states, although no difference can be perceived in their chemical qualities.† There would appear to be much probability in Dr. Prout's speculation that the small quantities of

* Several pots filled with earth, and containing different seeds, were placed on an insulated stand in a chamber, the air of which was kept dry by quick-lime. The stand was placed in connexion with a condensing electrometer. During germination, no electric disturbance was manifested: but the seeds had scarcely sprouted when signs of it were evident; and when the young plants were in a complete state of growth, they separated the gold leaves of the electrometer half an inch from each other. It was calculated by him that a vegetating surface of 100 metres square in extent produces in a day more electricity than would be sufficient to charge the strongest battery; and he not unreasonably considers that the growth of plants may be one of the most constant and powerful sources of atmospheric electricity.

† Annales de Chimie. Tom. LVII.

mineral bodies, usually regarded as accidentally present in the vegetable tissues, may have an important influence on their properties and actions. It has been shown by Sir J. Herschel that a force of 50,000 times that of gravity may be instantaneously generated, by the action of galvanism on an amalgam of mercury with a millionth part of its weight of sodium; and it cannot be denied, therefore, that the minutest admixture of ingredients may completely reverse the electrical and, consequently, the chemical relations of large masses of organised matter. All the vegetable tissues seem to have mineral matter so universally distributed through them, that it constitutes a skeleton which will retain its form after the destruction by heat of the organised and combustible portions of the structure; and these minute portions of matter may undoubtedly contribute to the production of those striking differences in the properties of bodies having apparently the same chemical composition, which at first sight appear so mysterious.

Electricity in Animals.

501. All that has been said of the effects of vegetation in producing a disturbance of electric equilibrium, will manifestly apply to the nutritive processes of animals also; and there is no deficiency of indications that such is the case. Thus, Donné found that the skin and most of the internal membranes are in opposite electrical states; and Matteuci has seen a deviation of the needle amounting to 15° or 20°, when the liver and stomach of a rabbit were connected with the platinum ends of the wires of a delicate galvanometer. It may be questioned whether or not the differences in the secretions of these parts were the cause or the effects of their electric conditions. According to Matteuci, it could not be by their chemical action on the wires that the manifestation was produced, since it became very feeble or entirely ceased on the death of the animal. These experiments are confirmatory, as far as they go, of Dr. Wollaston's theory respecting secretion. Observing the connection between electricity and chemical action, he was led to think that all the secretions in the body are the effect of electrical agency acting in various modes; and that the qualities of each secretion point out what species of electricity preponderated in the organ which forms it. Thus, the existence of free acid in the urine and gastric juice, and of free alkali in the bile and saliva, mark the prevalence of positive electricity in the kidneys and stomach; whilst an excess of negative electricity is indicated in the liver and salivary glands, —and so far the hypothesis is consonant with facts; many more observations, however, must be made on the natural and diseased conditions of the secreting organs before it can be substantiated.

502. From experiments on the human subject, it would appear that the living body would be never in perfect equilibrium with those around it, were this not constantly maintained by free contact with them; thus, if two persons, both insulated, join hands, sufficient electricity is developed

to affect the electrometer. Some electric disturbance is manifested by almost every individual, if it be carefully sought for. In men it is most frequently positive; and irritable men of sanguine temperament have more free electricity than those of phlegmatic character; whilst the electricity of women is more frequently negative than that of men. Some individuals exhibit these phenomena much more frequently and powerfully than others. There are persons, for instance, who scarcely ever pull off articles of dress which have been worn next the skin, without sparks and a crackling noise being produced, especially in dry weather; this may, however, be partly due to the friction of these materials on the surface and with each other, as it has been proved to be greatly influenced by their nature. The most remarkable case of the generation of electricity in the human subject at present on record, is one lately related in America.* The subject of it, a lady, was for many months in an electric state so different from that of surrounding bodies that, whenever she was but slightly insulated by a carpet or other feebly-conducting medium, sparks passed between her person and any object which she approached. From the pain which accompanied the passage of the sparks, her condition was a source of much discomfort to her; when most favourably circumstanced, four sparks per minute would pass from her finger to the brass ball of the stove at a distance of $1\frac{1}{2}$ inch. The circumstances which appeared most favorable to the generation of electricity were an atmosphere of about 80°, tranquillity of mind, and social enjoyment; while a low temperature and depressing emotions diminished it in a corresponding degree. The phenomenon was first noticed during the occurrence of a vivid Aurora Borealis; and though its first appearance was sudden, its departure was gradual. Various experiments were made with the view of ascertaining if the electricity was generated by the friction of articles of dress; but no change in these seemed to modify its intensity.

503. There seems little doubt that Electricity may be generated, not merely by the organic functions, but by changes more peculiarly connected with the animal powers; though it may be regarded as even then immediately dependent upon those nutritive processes, the constant action of which seems necessary to furnish the conditions required for any sensorial or motor phenomenon. It is possible, too, that the mere contact of different tissues may produce electrical manifestations; for Humboldt states that feeble contractions are produced in the leg of a frog by touching the nerve and muscle at the same time with a fresh portion of muscle. As long as the muscular fibre of animals retains its irritability, it may be used as a very delicate test of the disturbance of electric equilibrium, since this produces in it contractions similar to those which are occasioned by the stimulus naturally transmitted to it through the nervous system. Hence some have supposed these two agents, electricity and nervous

* American Journal of Medical Science, January, 1838.

influence, to be identical; but this is probably an untenable theory, as will be shown hereafter (§ 586). It is maintained, however, that electricity is developed when muscular action is excited by nervous influence;—Prevost and Dumas having witnessed considerable deviations of the index of an electrometer, of which one wire was plunged in the muscles of a frog's leg, and the other applied red-hot to the nerves so as to produce muscular contractions; and the same individuals having subsequently found that needles plunged into the muscles became sufficiently magnetic, during the contractions excited by stimulating the spinal cord, to attract iron filings by their projecting extremities.* An exception has very justly been taken to the first experiment, on the ground that the chemical action of the red-hot wire upon the tissues may have been sufficient to influence the galvanometer; and even the second cannot be regarded as altogether free from sources of fallacy, since the elevation of temperature which has been shown by Becquerel to occur during muscular contraction may have been the cause of the disturbance of the electric state. The utmost that is *proved* by either of them, however, is that electricity is generated during the action of the nerves upon the muscles; and to this doctrine there seems no reason to refuse assent.

504. When the facts already stated, respecting the various methods by which electricity may be generated in the living animal body, are kept in view, the peculiar cases in which it is developed to an excessive amount will appear less extraordinary; though there is still much room for investigation, before the conditions upon which these phenomena are immediately dependent can be ascertained. It is remarkable that nearly all the animals capable of accumulating electrical influence, and of discharging it at will in a violent form, belong to the class of Fishes; none among the Mammalia, Birds, or Reptiles being provided with any special apparatus for the purpose. Some Insects and Mollusca have been said to have communicated sensible shocks, but few details have been given on the subject. About six species of Fishes are known to possess electrical properties; and it is curious that they belong to tribes very dissimilar from one another, and that, though each has a limited geographical range, one species or other is found in almost every part of the world. Thus, the two species of *Torpedo*, belonging to the Ray tribe, are found on most of the coasts of the Atlantic and Mediterranean, and sometimes so abundantly as to be a staple article of food. The *Gymnotus*, or electric Eel, is confined to the rivers of South America. The *Silurus* (more correctly the Malapterurus), which approaches more nearly to the Salmon tribe, occurs in the Niger, the Senegal, and the Nile. The *Trichiurus*,† or Indian Sword-fish, is an inhabitant of the Indian Seas; and the *Tetraodon*

* Philosophical Magazine, March, 1838.

† There is some doubt, however, as to the real character of the fish to which this name has been given.

(one of a genus allied to the Diodon or globe-fish,) has only been met with on the the coral banks of Johanna, one of the Comoro Islands.

505. These fishes have not all been examined with the same degree of attention; but it seems probable that the phenomena which they exhibit, and the structural peculiarities with which they are connected, are essentially the same in all. The Torpedo has, from its proximity to European shores, been most frequently made the subject of observation and experiment. The peculiar characteristic of all is the power of giving, to any living body which touches them, a shock resembling in its effects that produced by the discharge of a Leyden jar. This is of very variable intensity in different species and individuals, and at different times. The Gymnotus will attack and paralyze horses, as well as kill small animals; and the discharges of large fish (which are 20 feet long) sometimes prove sufficient to deprive men of sense and motion. The effects of the contact of the Torpedo are less severe, and soon pass off; but the shock is attended with considerable pain when the fish is vigorous. The electrical organs appear to be charged and discharged to a certain extent at the will of the animals. Their power is generally exerted by the approach of some other animal or by some external irritation; but it is not always possible to call it into action even in vigorous individuals. It usually diminishes with the general feebleness of the system, though sometimes a dying fish exerts considerable power. All electrical fishes have their energy exhausted by a continued series of discharges; hence it is a common practice with convoys in South America, to collect a number of wild horses and drive them into the rivers in order to deprive the fishes of the power of injuring them when they pass. If excessively exhausted, the animals may even die: but they usually recover their electrical energy after a few hours' rest.

506. That the shock perceived by the organs of sensation in man is really the result of an electric discharge, has now been fully established. Although no one has ever seen a spark emitted from the body of one of the fish, it may be easily manifested by causing the Gymnotus to discharge through a slightly interrupted circuit, and late observers have been able to obtain one from the Torpedo also. The galvanometer is influenced by the discharge of the Torpedo, and chemical decomposition may be effected by it,* as well as magnetic properties communicated to needles. It seems essential to the proper reception of the shock, that two parts of the body should be touched at the same time, and that these two should be in different electrical states. The most energetic discharge is procured from the Torpedo, by touching the back and belly simultaneously, the electricity of the dorsal surface being positive, and that of the ventral negative; and by this means the galvanometer may be strongly affected, every part of the back being positive with respect to every part of the

* Dr. John Davy, Phil. Trans., 1834.

opposite surface. When the two wires of the galvanometer are applied to the corresponding parts of the two sides of the same surface, no influence is manifested; but, if the two points do not correspond in situation, whether they be both on the back or both on the belly, the index of the galvanometer is made to deviate. The degree of proximity to the electric organ appears to be the source of the difference in the relative state of different parts of the body; those which are near to it being always positive in respect to those more distant. Dr. Davy found that, however much torpedos were irritated through a single point, no discharge took place; and he states that, when one surface only is touched and irritated, the fish themselves appear to make an effort to bring, by muscular contraction, the border of the other surface in contact with the offending body; and that this is even done by fœtal fish. If a fish be placed between two plates of metal, the edges of which are in contact, no shock is perceived by the hands placed upon them, since the metal is a better conductor than the human body; but, if the plates be separated, and, while still in contact with the opposite sides of the body, the hands be applied to them, the discharge is at once rendered perceptible, and it may be passed through a line formed by the moistened hands of two or more persons, the extremities being brought into relation with the opposite plates.

507. It has been ascertained by experiment that the manifestation of this peculiar power depends upon the integrity of the connexion between the nervous centres and certain organs peculiar to electrical fishes. In the Torpedo these organs are of flattened shape and occupy the front and sides of the body, forming two large masses which extend backwards and outwards from each side of the head. They are composed of two layers of membrane, between which is a whitish soft pulp, divided into columns by processes of the membrane sent off so as to form partitions like the cells of a honey comb; the ends of these columns being directed towards the two surfaces of the body. They appear to be again subdivided horizontally by more delicate partitions, which form each column into a number of distinct cells; the partitions are extremely vascular and profusely supplied with nerves. The fluid contained in the electrical organs forms so large a proportion of them, that the specific gravity of the mass is only 1026, whilst that of the body in general is about 1060; and, from a chemical examination of its constituents, it appears to bear a very considerable analogy with the substance of the brain.* The electrical organs of the Gymnotus are essentially the same in structure, though differing in shape in accordance with the conformation of the animal; they occupy one-third of its whole bulk and run along nearly its entire length; there are, however, two distinct pairs, one much larger than the other. In the Silurus there is not any electrical organ so definite as those just described;

* Matteuci, Philos. Magazine, March, 1838.

but the thick layer of dense cellular tissue, which completely surrounds the body, appears to be subservient to this function; it is composed of tendinous fibres interwoven together and containing a gelatinous substance in their interstices, so as to bear a close analogy with the cellular partitions in the special organs of the Torpedo and gymnotus. The organs of the other known electrical fishes have not yet come under the notice of any anatomist.

508. In all these instances, the electrical organs are supplied with nerves of very great size, larger than any others in the same animals and larger than any nerve in other animals of like bulk.* The integrity of the nerves is essential to the full action of the electrical organs. If all the trunks be cut on one side, the power of that organ will be destroyed, but that of the other may remain uninjured. If the nerves be partially destroyed on either or both sides, the power is retained by the portion of the organs still in connexion with the brain. The same effects are produced by tying the nerves as by cutting them. Slices of the organ entirely separated from the body, except by a nervous fibre, may even exhibit electrical properties. Discharges may be excited by irritation of the brain when the nerves are entire, or of the part of the divided trunk distributed on the organ; but, on destroying the fourth lobe of the brain, which is peculiarly connected with respiration, the electric power of the animal ceases entirely. It is remarkable however that, after the section of the electrical nerves, torpedos appear more lively than before the operation, and actually live longer than others not so injured, but which were excited to discharge frequently. Poisons which act violently on the nervous system have a striking effect upon the electrical manifestations of these fish; thus, two grains of muriate of Morphia were found by Matteuci to produce death after about ten minutes, during which time the discharges were very numerous and powerful; and Strychnia also excited powerful discharges at first, succeeded by weaker ones, the animals dying in violent convulsions.*

509. That the power which causes muscular contraction is the same which enables the Electrical fishes to give sensible manifestations of Electricity, cannot, after the facts now enumerated, be deemed an improbable supposition. The connexion of the organs specially appropriated to these functions with the nervous system, the dependence of their functions upon the integrity of this connexion and upon the will of the animal, the influ-

* They all arise in the Torpedo from the cranial portion of the cerebro-spinal axis; of these the two first issue from the cranium in close proximity with the 5th pair, and have been regarded as belonging to it, although their real origin is different; and, from the distribution of the third electrical nerve to the stomach after sending its principal portion to the electrical organ, it would seem analogous to the 8th pair. The electrical nerves in the Gymnotus are believed to arise from the spinal marrow alone; and those of the Silurus are partly intercostals and partly belong to the 5th pair.

† Matteuci,—Philos. Magazine, Feb., 1838.

ence of stimulation applied to the nervous centres or trunks, the effect of ligature as well as section of the nerves, and the corresponding effects of poisonous agents in both cases, all tend to show an analogy so strong that it is scarcely possible to refuse assent to the identity of the influence communicated by the nervous system in each case. Still, however, no proof can be derived from this source of the identity of nervous influence with galvanic, or any other form of electricity; since all that can be stated is, that by the influence of the nervous system on one organ, electricity is generated,—and that by its action on another, sensible contraction is produced. The property of generating electricity *may be* as much peculiar to the special organs which we find for accumulating it, as that of contractility to muscular fibre; and its manifestation may, after all, be dependent upon some molecular changes excited by the influence of the nerves, to which the evolution of electricity may be due. Upon this subject we can at present only speculate.

510. Regarding the uses of the Electrical organs to the animals possessing them, no very certain information can be given. It is doubtful to what extent their power is subservient to the prehension of food, which was once supposed to have been their principal object; since it is known that the Gymnotus eats very few of the fishes which it kills by its discharge; and young Torpedos kept by Dr. Davy for five months ate nothing, though supplied with small fishes both dead and alive, but nevertheless increased in strength and in electrical energy. Dr. D. believes that it may assist the function of respiration by decomposing the water in the neighbourhood of the gills, when the animal, being buried in sand or mud, might be unable to obtain the requisite supply of oxygen in the ordinary way; but its chief use he considers to be to guard the fish from its enemies. Another function, however, may not improbably be influenced by it,—that of digestion; and this in two ways. It is well known that the vital properties of living tissues are so completely destroyed by a violent electric discharge, that they are disposed to pass more readily than in other cases into decomposition, the incipient stage of which is favourable to digestion; the shortness of the intestinal canal of the torpedo would seem to render some assistance of this kind peculiarly necessary. The process of digestion may also be aided by the continued action of electricity through the nerves of the stomach, which have been mentioned to be peculiarly connected in the Torpedo with those of the Electrical organs; a supposition which derives some conformation from the fact mentioned by Dr. Davy, that digestion appeared to be arrested in an individual which had been exhausted by frequent excitement to discharge itself; it should be kept in view, however, that the general depression of the system may have been the cause of the check put to the process. It is not unlikely, as Dr. Roget has suggested, that the electrical organs may communicate to the fish perceptions of electrical states and

changes in the surrounding bodies (very different from any that we can feel), in the same way as other organs of sense convey perceptions with regard to light and sound. Such perceptions may be conceived to be very useful and pleasurable to animals living in the dark abysses of the waters.

CHAPTER XIII.

REPRODUCTION OF ORGANISED BEINGS.

General Considerations.

511. If the changes which living beings undergo during the period of their existence, and the termination of that existence by the separation of their clements at a period more or less remote from their first combination,* be regarded as distinguishing them in a striking and evident manner from the masses of inert matter which surround them, still more is their difference manifested in the extraordinary series of processes which constitute the function of Reproduction. It need scarcely be pointed out that the Earth would soon be depopulated of its tenants, were not the power of continuing their respective races, by the creation of new beings, superadded to those with which individuals are endowed, for the maintenance of their own perfection of structure and activity of condition. It was the communication of this power to the first-created organism of each species which occasioned its multiplication and diffusion; it is by its continued operation that the causes destructive to the existence of individuals are prevented from affecting the permanency of the race; and it is the failure of the conditions requisite for its exercise which leads to the extinction of the species, or the disappearance of the race from the surface of the globe.

512. A very unnecessary degree of mystery has been spread around the exercise of this function, not only by general enquirers, but by scientific physiologists. It has been regarded as a process never to be comprehended by man, of which the nature and the laws are alike inscru-

* This change appears to be what essentially constitutes the *Death* of any *individual* part. So long as a tissue retains its normal constitution, and is acted upon by the requisite stimuli, so long it may perform vital actions; even though the organism in general should have undergone that dissolution of its functions, by the destruction of some essential link in their chain, which constitutes *Somatic death*. Any cause, therefore, which produces the latter, will occasion the former, only by the interception of those renovating changes which are necessary to maintain the organisation of every part, and to prevent it from undergoing spontaneous decomposition even during life. (See § 18, and 153-4).

table. A fair comparison of it, however, with other functions, will show that it is not in reality more wonderful or more recondite than any one of them;—that our acquaintance with each depends upon the facility with which it may be submitted to investigation;—and that, if properly enquired into by an extensive survey of the animated world, the real character of the process, its conditions, and its mode of operation, may be understood as completely as those of any other vital action. It is hoped that, in the following outline, the philosophical pursuit of such an enquiry will be shown to be perfectly consistent with the purest delicacy of feeling, so that the general as well as the professional reader may enter upon it without reserve.

513. It has been formerly stated (§ 228) that, in its most general condition, the function of Reproduction may be considered a part of that of Nutrition; since, like almost all the members of the Vegetable Kingdom, the lowest and simplest Animals are made up of a number of similar parts, which are capable, if separated naturally or artificially, of maintaining an independent existence, although originally composing but a single individual. This plan of reproduction combined with nutrition is especially manifested in the simpler Algæ and Fungi, where every distinct cell may be regarded as an extension of the original being, or as constituting a new one. These are instances of peculiarly *homogenous* structure, each part living for itself, and contributing but little to the maintenance of others. The more *heterogeneous* (§ 200) a fabric becomes, however, that is to say, the more difference is manifested in the structure and properties of its individual parts,—the less title has *any one* to be regarded as a separate individual, since it cannot maintain an independent existence, nor reproduce the entire structure. In the higher Plants, for instance, where the absorbent surface is distinct from the exhalant and respiratory surface, neither one of these is sufficient to maintain life independently of the other, and no part can separately exist which does not combine both. But, even here, the simplicity of this combination occasions it to be very frequently repeated through the fabric: and each leaf-bud has the power, when removed from the parent, of reproducing the entire structure, if the essential conditions be afforded to it. Although, therefore, a more *special* reproductive apparatus is here developed, the function still retains, to a certain extent, the *general* form which originally characterised it; and when this special apparatus is explained, it will be perceived to be a concentration, as it were, of that general form, and not something entirely new and superadded to it.

514. Among Animals, also, the same connexion of the Reproductive with the Nutritive function, may be very distinctly traced; and although it is only in the lowest that the *general* condition of the former is manifested so apparently as in plants, it may still be traced without difficulty even in the highest. We have seen that, among the classes composing the

sub-kingdom Acrita, there is usually an extraordinary capability in each part of the fabric to reproduce the whole; the minute cuttings of a single Hydra, for instance, developing themselves into single polypes, and a portion of the gelatinous flesh of one of the compound Polypifera gradually becoming a complex and massive structure. In these classes we observe, as in the Algæ, an occasional spontaneous separation of parts of the parent structure, for the production of new ones; and this may be regarded as leading us towards the more special form which the reproductive apparatus assumes, both in them and the higher animals. Among many of the lower Articulata, also, the segments of the body appear to be capable of producing new individuals; and in some of the marine Annelida, their separation is said to take place spontaneously, like that of the articulated Algæ. But, among the higher vermiform tribes, the power of maintaining a separate existence, and of reproducing the entire structure, is limited to the division including the head. Proceeding to still more heterogeneous beings, it is found that a mutilation apparently less in degree is fatal to the existence of both portions, because the organ which is removed has no repetition in the remainder of the fabric, and is quite incapable of developing new parts entirely dissimilar to itself. Nevertheless it may be perceived that, even in the highest animals, there is considerable power of regenerating lost parts, which may be regarded as the remnant of that general capability of reproduction which is so remarkable in the lower, and which has here been superseded by the development of a more special apparatus. The formation of new claws and legs by Crustacea, Spiders, &c., has already been noticed (§ 84, 5); and the same thing takes place in many species of Reptiles, especially among the order Batrachia. In the Salamander, for example, new legs with perfect bones, nerves, muscles, &c., are reproduced after the loss or severe injury of the original ones; and, in the Triton, a perfect eye has been formed to replace one which had been removed. In the true Lizards, the tail when lost appears to be restored; the new part contains no perfect vertebræ, however, but merely a cartilaginous column like that of the lowest fishes. In Mammalia in general, as in man, the power of reproducing entire organs appears to be much less considerable; but each tissue is capable of regenerating that of its own kind; and, as this process of renovation is constantly taking place in the living body, nutrition has been not unjustly spoken of as a *perpetual generation*. It would seem that in some individuals this regenerating power is retained to a greater degree than by the class at large;* and that in the early period of development, as in

* One of the most curious and well-authenticated instances of this kind is related by Mr. White in his work on the Regeneration of Animal and Vegetable substances, 1785, p. 16. "Some years ago, I delivered a lady of rank of a fine boy, who had two thumbs upon one hand, or rather, a thumb double from the first joint, the outer one less than the other, each part having a perfect nail. When he was about three years old, I was desired to take off the

the lower classes of animals, it is more decided than in the perfect condition. On this supposition, at least, it is easy to account for the occurrence of supernumerary parts, and even for the duplicity of a considerable portion of the body,—as in monsters possessing two heads with one trunk, or one head with two trunks, or a superabundance of extremities. These are just such as may be produced in the polype by the partial division of its body. Perfect double monsters, however, where two complete bodies exist (as in the Siamese twins), obviously result from the union of two separate germs.

515. The separation of parts of the parent structure into new individuals, whether this be naturally or artificially effected, constitutes, therefore, the simplest and most general form of Reproduction, and that which is connected most closely with the function of Nutrition. It may be manifested in various ways,—as in the separation of the whole structure into portions, which takes place in such articulated Algæ as the Diatoma (§ 69),—the formation of gemmæ or bulbs (§ 61) by the Marchantia, Mosses, &c., which drop off when mature, and continue the race, or remain attached to the parent;—the evolution of buds in the flowering plant, which may or may not continue as part of the individual structure, —the production of young Polypes from the sides of the parent (§ 115)—the spontaneous division into two equal halves which is the principal means of reproduction in several animalcules,—and the separation of the parts of Annulose animals just now adverted to. On comparing all these instances together it will be seen that they all correspond in essential character, the new being originating in a peculiar development of that which previously constituted an integrant part of the parent structure; although it may be sometimes rather difficult to say which of the beings that have been the subjects of a process of this kind is to be considered as the parent. Upon this general condition of the function, the more special one may be regarded as engrafted; and this consists in the development, from some particular spot in the parent structure, of a germ, which from the first is destined to reproduce the being, and which, if not separated from its parent in the ordinary course, ceases to exist. All the forms of *sporuliferous*, *oviparous*, *and viviparous* reproduction may be reduced to this general expression; and they will be found to coincide in this essential particular, although differing in the mode and degree of the assistance

lesser one, which I did; but to my great astonishment it grew again, and along with it, the nail. The family afterwards went to reside in London, where his father showed it to that excellent operator, William Bromfield, Esq., surgeon to the Queen's household; who said, he supposed Mr. White, being afraid of damaging the joint, had not taken it wholly out, but he would dissect it out entirely, and then it would not return. He accordingly executed the plan he had described, with great dexterity, and turned the bail fairly out of the socket; notwithstanding this, it grew again, and a fresh nail was formed, and the thumb remained in this state.'

provided for the development of the germ, when no longer organically united to its parent.*

516. These general views must not be concluded without allusion to two important questions regarding the production of living beings, viz. whether they are capable of originating from the mere combination of inorganic elements, by the process which has been termed *spontaneous* generation; or whether they may be evolved from organised beings dissimilar to themselves, through any irregularity in their functions, or by the incipient decay or degeneration of their tissues, by the process termed *equivocal* generation.† The affirmation of the first question has been maintained by many philosophers, who have regarded all matter as, in some sort, animated; and although it has been principally urged in reference to the lowest classes of beings, it does not seem possible to limit its application, if it be really valid. For it may be easily shown that facts of the same class as those which appear to support the belief that Fungi or Infusorial animalcules may be spontaneously developed, would lead to the supposition that the higher classes of plants and animals are subject to the same law.‡ But some naturalists of the present time are disposed to admit this also, and to account for the changes in the races of Plants and Animals which geological researches reveal, by the supposition that, as old species became extinct from natural causes, new ones might arise from the inherent tendency in all matter to become organised: and that an elephant or an oak (and why not a man?) might be produced by spontaneous or accidental combination of its elements.§

* It will be hereafter seen (§ 540) that the connection between a viviparous parent and the fœtus contained within its uterus, is very far from being of the same kind as that which it had with the ovum whilst in the ovary. In fact, that ovum first separates itself completely, as in birds or other oviparous animals; and though it subsequently derives its nutriment from the parent, by means of the new connection which it forms, that connection is more like that of a plant with the soil in which its roots ramify, than that of one part of the structure with another.

† These two terms have been used synonymously by many writers; but the distinction which is here drawn is an important one, and has been made by later physiologists.

‡ For an instance of this kind see § 155. The white clover which is there mentioned as appearing on the surface, wherever this is rendered alkaline, could only spring from seeds brought by the wind and developing themselves wherever the soil was favourable, or from germs pre-existing in the soil or in the alkaline matter: and this is all that is needed to account for the constant development of the parasitic Fungi upon decaying organised substances, and is much more easily supposed with regard to them, from the minuteness of their germs, and the provisions obviously made for their extensive diffusion.

§ Such a doctrine it is impossible to refute, otherwise than by an appeal to facts. No such new creations are known to us at the present time, and therefore it can only be argued from analogy that they ever existed. We may believe that there exists in all matter a tendency to become organised, without relinquishing the doctrine that, for the manifestation of such tendency, a previously existing organism is required, to collect and unite the scattered elements by the powers with which it alone is endowed. For the enunciation of this extraordinary doctrine, and the flimsy reasoning by which it is supported, see Dr. Weissenborn's paper on the subject in the Lond. and Edinb. Philos. Magazine, July, 1838. However well such speculations may

517. The second question, however, is one to which there is much difficulty in replying satisfactorily; and it would, perhaps, be better to leave it without decision of any kind until more extended researches shall have furnished more positive data. Our belief that the new beings formed by the process of reproduction always closely resemble the parent stock, is certainly founded upon a limited induction from observations made upon the higher classes of plants and animals. Reasons have already been given (§ 65, 68) for the opinion that the same germ may assume very dissimilar forms according to the circumstances under which it is developed; and, knowing as we do how readily the simpler classes of organised beings are affected by changes in their external conditions, it is not difficult to admit the possibility of their forms being thus greatly modified, as well as of the continued propagation of the varieties thus produced. Some very curious observations upon the reproduction of Lichens support this view. The special reproductive particles which are formed in the *shields* (§ 68) of the higher species are capable of developing themselves into the same specific forms: while the powdery matter of their surface, and of other individual parts of their structure, may separately exist in the condition of inferior species.* It appears very difficult, and indeed almost impossible, without some admission of this kind, to account for the production of parasitic plants and animals in the interior of others. That their germs have been conveyed from without into the situations where they are developed, must be held as a very forced supposition, when it is considered that they are often much larger than the vessels by which they must have been transported; and that, in many instances, the animals which produce them are not known to exist anywhere but in the living body. Entozoa have been found even in eggs; they also appear in various diseased states of vegetables; and they seem to be normally produced in certain parts of Mosses, &c., which have been supposed to be connected with the reproductive function. There is probably scarcely an animal in which parasites of this kind might not be discovered at some period of existence; and even the intestinal worms are themselves infested with Entozoa of inferior species. It is often very difficult, moreover, to distinguish between a degeneration of structure, and a growth entirely new; and there are some forms which appear to connect the two. Thus, the simple *acephalocyst* (§ 112) seems composed of nothing else than layers of condensed albumen; and it differs in nothing, but its want of connection with the surrounding parts, from the serous cysts which are morbid growths of no unfrequent occurrence in the animal body. And,

suit German taste, the English public is happily not yet quite ripe for them. That *species* have in all ages of the globe maintained their present uniformity and narrow limits of variation, the author is not disposed to assert; and he thinks that many facts tend to prove the relaxation, at former epochs, of the strictness of the laws which are at present regarded as governing their modification and reproduction. See § 545.

* Lindley's Natural System of Botany, p. 331-2.

on the other hand, the various forms of cancerous structure have been maintained, with some show of reason, to be of a parasitic character. The difficulty of distinguishing in plants between diseased growths and new organisms has been already alluded to (§ 66); and the appearance of certain apparently vegetable growths in the bodies of living animals adds to this difficulty.* Nor is such a hypothesis inconsistent with what is known of the nutritive processes in their normal and abnormal condition. It has been shown that all the solid tissues of the body are formed from its alimentary fluids; and observation of diseased actions shows us that portions of these fluids are capable of passing from an unorganised to an organised condition, by virtue of their inherent properties (§ 364). Now, although the new tissues thus formed usually become part of the general structure, by forming a connection with those in their neighbourhood, it is not difficult to suppose that a variation in this process might give rise to the production of a new individual of inferior form; especially when we bear in mind how closely the nutritive and reproductive functions are united in the lowest groups of living beings. It may be reasonably concluded, then, that if there is not yet sufficient evidence for the establishment of such a hypothesis, there is at least enough to prevent us from rejecting it as altogether absurd or untenable. From these general views we must now pass to the consideration of the function of Reproduction in its special form.

Reproduction in Vegetables.†

518. It is particularly necessary for the acquirement of accurate ideas on this subject, to discard all preconceived notions derived from the study of any one type of structure, and to form our opinions only from the facts which observation successively brings before us. And in regard to this, more than to almost any other of the functions, there is a peculiar advantage in first studying its simplest form, in order to obtain that knowledge of its essential character, which cannot be derived from its more complex conditions, without such an analysis as the nature of the enquiry forbids. It is desirable, also, to keep in view the principles which have been so frequently dwelt upon, of the gradual specialisation of the various functions witnessed in ascending the scale; for we shall find that, whilst

* Allusion is here made to such instances as that of the "Vegetating Wasp" of the West Indies. The insect (a species of Polystrix) is infected, while alive, with a parasitic Fungus (allied to Sphæria,), which gradually increases so much in size as to destroy the life of the animal; the author has seen specimens, in the possession of his friend Mr. J. Yates, in which the Fungus had protruded more than an inch from the body of the insect whilst alive. Similar occurrences have been noticed among other Insects in all stages of their development.

† The Author deems it just to himself to state that he should not have ventured to introduce the following doctrines (many of which he believes to be original) into the present work, had they not received the sanction of several eminent Botanists. He hopes to be able to publish before long a more complete Essay on the subject, which has been laid before the Royal Botanical Society of Edinburgh.

in the lowest and simplest plants, the whole structure partakes in the function of Reproduction, as well as in those of Absorption, Respiration, &c., a very small part is appropriated to it in the highest orders, but that part is destined to no other office. Thus, however paradoxical it may appear to say that the *Protococcus nivalis*, or any other simple plant, is all *pollen*, it will appear that this expression may be as legitimately applied to it as that of *all root*, which has been shown to be deserved by it (§ 246).

519. Each vesicle of the *Protococcus* contains a number of little minute granules, which may be observed to increase within the parent cell, and at last to rupture their envelope, and escape from its cavity. If their separation takes place in water, they are observed to have, for some time, a spontaneous motion in the fluid; and in their turn they develope themselves into new cells, which are burst asunder by the embryos contained within them. This, then, may be regarded as the simplest form of the special function of reproduction. The whole of the parent structure is concerned in the development and nutrition of the germs; and these, in liberating themselves from their envelope, at the same time destroy its individuality. The same process will be found to take place in the highest plants, with this difference,—that as the whole system is *not* concerned in the formation of the embryo, but only a very small portion of it, that portion alone ceases to exist as soon as its function is performed, the life of the parent remaining uninjured. In the higher Cryptogamia, the reproductive cells, containing the germs, are distinct from the rest of the structure, and are developed only from a particular part of it; they are denominated *spores*. And in the Phanerogamia this is also the case, the reproductive cells being there termed *pollen;* but an additional organ is here developed, for the purpose of receiving and nourishing the embryo on its first liberation, and of thus enabling it to advance ultimately to a more exalted condition than it could have attained if left to its own resources from the beginning. In all instances the reproductive cells have essentially the same character. They contain an immense number of minute granules, swimming in fluid, and endowed with a peculiar spontaneous motion, which may be observed both before and after their liberation.*

520. In the higher ALGÆ, where several cells unite together to form one individual, a certain separation of their functions takes place, some of the cells containing no reproductive granules or germs, and others

* This curious fact is a very strong argument in favour of the analogy here drawn between the *spore* and *pollen-grain*. The most remarkable instances of the motion are among the Algæ, where the reproductive cells and their contained granules are large, and occupy a large proportion of the plant. It has been noticed also in the spores of the higher Cryptogamia, and in the pollen of flowering plants. When these cells are brought into contact with water, they burst and expel their contents with considerable force, and the granules exhibit a more or less evident motion in the surrounding fluid.

evolving them most abundantly. This may be particularly noticed in the Confervoid tribes; and it is among them that the phenomenon of spontaneous motion is most obviously presented. The granules are first seen on the interior walls of the fertile cells, as unformed green dots, which gradually assume a more definite aspect, and at last separate themselves from their attachment, and move freely within the cell. After a period of continued restlessness, one part of the containing cell is observed slightly to protrude, and in a short period to open in such a manner as to permit the exit of the granules. These move very regularly for some time in the surrounding fluid (Fig. 61, A); but at last they attach themselves, and commence their development into new plants. The first change is one of form only, the granule becoming elongated into an oval (Fig. 62, *a*). After a little time, the green matter which it contains is separated by a delicate partition, which subsequently becomes more decided; and, by a succession of divisions, and the increase of each cell thus formed, a prolonged filament is produced (*b*, *c*). A precisely similar processes takes place in many of the marine Algæ, such as the *Ulva clathrata*, which has usually from three to six granules enclosed in each of the cells forming its frond; these escape by a pore, and exhibit a certain degree of spontaneous motion, although not so evidently as those of the Confervæ. Their early development, however, follows exactly the same course; for the first change in the granules is manifested by their elongation into filaments, so that the young plant resembles a Conferva. Subsequently, however, these filaments present a double row of cells, and gradually increase in breadth, so as to form the foliaceous expansion peculiar to this tribe. The immediate cause of the movement of these reproductive granules has not been ascertained. They do not seem possessed of anything resembling cilia; but Agardh imagines that they are propelled by the vibrations of a little beak or prolongation with which they appear to be provided.*

521. These evident movements are not, however, exhibited by the reproductive granules of all the Algæ; for those of the *Fucoideæ* (a tribe which includes many of the common sea-weeds) would seem to be entirely inactive. The members of this family are chiefly inhabitants of the depths of the ocean, and the simple gravitation of their embryos appears to conduct them to a place fit for their development. In the more complex organisms of this class we find a considerable specialisation in the Reproductive system; since, instead of the granules being liberated from the cells of the whole structure, a particular portion of the surface is appropriated to their formation, or even special external organs are evolved as receptacles for them. Thus, in the *Florideæ*, the granules are either collected into groups on the general surface of the frond (foreshadowing the *sori* of the Ferns), or on little separate leaflets, or enclosed

* Annales des Sci. Nat. N. S. Botan., Octobre, 1836.

in capsules which may be regarded as analogous to the *spores* of the higher Cryptogamia, although much larger in proportion to the size of the entire fabric. In such plants as the common *Fucus vesiculosus* (bladder-wrack), the reproductive granules are not only enclosed in distinct capsules, which separate altogether from the parent when mature, but these capsules are themselves evolved from a special receptacle. Still the same plan is followed in its essential particulars; for the germs are, at the proper epoch, liberated from the capsules by a pore, just as in the Conferva, and commence their development in the same manner. It is, then, evident that the principal difference between the reproductive cell of the Conferva, and that of the Fucus, consists in this;—that the former constitutes an integrant part of the general structure, (in the Protococcus, indeed, it forms the whole of it), the function it has to perform not yet being limited to a portion of the plant;—whilst in the latter, the reproductive cellules are developed only in particular situations, (several being united in a common receptacle, the first indication of a *theca*,) and their separation does not interfere with the nutritive functions of the plant.

522. In the LICHENS and FUNGI the function appears to be performed in a manner essentially the same with that already described. Beginning with the lowest in each tribe, we find the reproductive granules contained in the cells which constitute the entire plant; and, as we ascend towards their higher forms, we observe them gradually restricted to particular spots, and enclosed in special envelopes. In some Lichens, however, which never evolve a special reproductive apparatus, we find propagation carried on by little bodies analogous to *buds* or *gemmæ*, which are separated from the surface. This is never the case in the Fungi, whose whole structure appears devoted to the perfection of the reproductive system. The more simple forms of this group have already been noticed (§ 64); and from these we might pass, by almost imperceptible gradations, to the most complex, such as the common Mushroom. Here a separation between the nutritive and reproductive systems is effected by the stalk which elevates the *pileus* or cap above the roots; in the *hymenium* or fructifying membrane that forms this portion, are found certain elongated tubes lying side by side, which have received the name of *asci;* and these contain the fertile cells or spores, which enclose the granules or real germs (Fig. 57).

523. Passing from these to MOSSES, we find the spore-cases or *thecæ*, (as they are termed in the higher Cryptogamia), more completely separated from the nutritive system. Their structure and position in this group, as also in the *Marchantia* and the FERNS, have been already sufficiently described (§ 59-61); but though these are so variable, the essential character of their contained parts remains the same in all. We observe, however, in ascending the scale, that each spore occupies a smaller and smaller proportion of the entire plant, and that the reproductive system

becomes more and more independent of the nutritive. The development of the spore, however, must be more particularly described: its early stages will be found to correspond essentially in all the classes here brought together; and the ultimate differences seem to depend principally upon the degree of development which each attains. Although Botanists have laboured to discover the existence of a second set of reproductive organs in these classes, analogous to those which exist in Phanerogamia, none such has been demonstrated*; and the notion that reproduction cannot take place without a reaction between two different systems, is founded only on the observation of the process as performed in the higher plants, and is entirely inconsistent with what has been hitherto witnessed. The capability of producing a germ which may develope itself into a new plant, seems to be an essential property of the cells which have been designated as reproductive; just as the power of developing additional vesicles, which may remain parts of the same organism, is an attribute of those which belong to the nutritive system. The spore appears to consist, like the pollen-granule, of two coats, of which the outer one is somewhat dense, and the inner of extreme delicacy. The contained granules, when the spore is mature, may be seen to swim freely in the fluid which fills the cells. The first change which is noticed during the development of the spore, is the rupture or separation of the outer coat, and the protrusion of the inner one, in the form of filamentous tubes; of these several are seen in the Mosses, but usually one or two only in the Marchantia and in Ferns (Fig. 53, *b*). These tubes are seen to contain the moving green granules which appear to be the germs of the future structure; and insulated portions of them are capable of reproducing the plant, when separated from the original cell. By the development of these granules, new cells are formed, which unite together into single rows, and these afterwards increase laterally, so that a foliaceous expansion is formed (Fig. 63, *a*, *b*, *c*, 64).† In the germination of Marchantia, observed by Mirbel,‡ the cells at first formed do not exhibit any particular regularity of apposition (Fig. 53); but afterwards they become compressed against each other, and adhere closely. In these instances the new plant evidently takes its origin from the germs contained within the spore or reproductive cell, although no absolute emission of them occurs as in the Algæ. The foliaceous expansion first formed gradually assumes, in the Marchantia, the aspect of the perfect plant, radical fibres being protruded from its lower surface, and stomata being formed on the upper; but in the Ferns it has only a temporary character, and decays away when the true stem and leaves are evolved from it in the manner represented in

* The so-called *anthers* of Mosses, Liverworts, &c. have not, in the opinion of the best Cryptogamic Botanists, any influence on the production of germs from the thecæ.

† See Mr. Henderson's paper in the Magazine of Zoology and Botany, vol. i.

‡ Nouv. Ann. du Museum, tom. iii.

(Fig. 65). This may be termed the *primary frond;* and it will be found strictly analogous to the cotyledon or seed-leaf (§ 49) of flowering plants. The Marchantia, therefore, stops short at a stage beyond which Ferns pass; and consequently presents as its permanent condition what is only a transitory form of higher structures.

524. In a little group of plants termed *Marsileaceæ*, which have been ordinarily associated with the Ferns, we have the first appearance of any organ superadded to those designed for the evolution of the spore. This consists of what is termed an *ovule*, which is a receptacle adapted to receive the germ, and to forward its development by means of the store of nutriment it contains. In the Marsilea, the *thecæ* containing the spores (analogous to the *anthers* of flowering plants) are enclosed, with the *ovules*, in a common envelope (Fig. 74); and the communication between them seems to be direct (Fig. 75). The spores will not of themselves produce new plants, neither will the ovules; since the germs contained in the former require to be assisted in their development, and the latter must be *fertilised* by the introduction of a germ. This process appears here a very simple one, being effected by the direct communication which exists between the two organs. In the flowering plants, of which this may be regarded as one of the least developed forms, a more complex apparatus is usually found; but it only serves the same purpose in a different manner.

525. According to the views here taken, therefore, the essential part of the reproductive system of the PHANEROGAMIA consists, as in the Cryptogamia, of an organ for the production of vesicles containing germs, here termed the *anther;* and the part which distinguishes it is superadded, for the purpose of giving that assistance to the early development of these germs, which seems in all instances to be required where a complex and highly-organised structure is ultimately to be produced. Late researches on the process of fertilisation have shown that the function of the parts which constitute the *pistil*, is simply to convey to the ovules contained in the ovarium at its base the germs liberated from the pollen-grain. When this is emitted by the Anther (as the spore from the theca of a Cryptogamous plant), it does not immediately become subservient to the influence of external agents, and owe its subsequent evolution to the nutriment which it obtains from the surrounding elements alone; but the germs it contains are received into another part of the structure, and supplied not only with present aliment, already prepared for organisation, but with a store which may serve to continue their development for some time after their final separation from the parent. The changes which take place in the pollen-grain when it is brought in contact with the moist surface of the stigma, are exactly equivalent to those which have been described as occurring in the spore. The outer envelope separates in one or more points; and the inner tunic is protruded in the form of

tubes, which contain some of the granules that might have been previously seen freely moving within their cell. These tubes insinuate themselves (in the manner represented in Fig. 68) along the lax tissue of the style, and may be traced to the ovarium. There they enter the openings which, up to that time, have been left in the membranes of the ovules, in whose cavities nothing but a quantity of fecula and mucilaginous fluid previously existed; but one of the granules in the pollen-tube thus introduced into each ovule gradually increases at the expence of these materials, and finally either occupies the whole ovulum by the absorption of the albumen into its cotyledons, or shares it with the separate albumen (§ 50). The maturity of the seed is a period of cessation in its actions; and it then arrives at a state of development in which it may remain dormant for a considerable period,—until, in fact, the stimuli requisite for its further evolution shall be supplied to it.

526. In the early development of the embryo of the Phanerogamia within the ovule, we may trace an essential correspondence with the evolution of the germs of the Ferns or other Cryptogamia; and we may also trace a general analogy between its transitory conditions at different epochs and those which are permanent in the lower classes. In its earliest recognisable appearance, it is a mere vesicle filled with a whitish fluid, and may be regarded as representing the *Protococcus* or some other equally simple plant; but as new cells are developed, it becomes analogous to Algæ of somewhat more complex structure. It soon begins, however, to expand laterally, so as to form a Cotyledon, which will be single or double according to the class to which it belongs (*a*, Figs. 66, 7). When the seed is mature and separated from the parent, it requires warmth, moisture, and the presence of oxygen to stimulate its further development, and to enable it to convert into organised structure, the store of aliment which it contains. Where the cotyledons are fleshy (the albumen having been taken into their substance), they shrivel and fall off as soon as their store is exhausted; but where they are leafy (the albumen remaining separate), they come to the surface, acquire a green tint, possess stomata on their cuticle, and perform for a time the functions of true leaves, until these are evolved. As yet, the fibro-vascular system is but imperfectly developed, the young plant consisting of but little more than cellular substance; and at this period it may be regarded as exactly representing the Marchantia and other similar plants, which possess stomata on their fronds or foliaceous expansions; since these fronds, being analogous to the *primary fronds* of Ferns, are truly *permanent Cotyledons*.* In a short time the plumula (§ 50) ascends, bearing with it the rudimentary leaves, which, becoming developed, repeat in a much more perfect manner

† The very curious analogies to the animal kingdom here presented, have already been pointed out in § 385 and 417; and the former may be referred to for a curious correspondence between the condition of a germinating seed and a growing Fungus.

the functions previously performed by the cotyledons, and commence the formation of woody fibre. The plant is now arrived at a stage of its growth which may be compared with that of the Ferns; it is not until a somewhat later period that we can trace the true spiral vessels, which are confined to flowering plants; and we must wait for full maturity before that special form of the reproductive system is evolved, which marks the entire completion of the development.

527. In tracing the progressive evolution of the special Reproductive apparatus in Plants, we observe that although it is gradually separated from the nutritive system, in proportion as we ascend the scale, it is never entirely disconnected with it. It was formerly stated that all the parts of the flower may be regarded as metamorphosed leaves (§ 54); or, more correctly, as metamorphosed forms of the elements of which leaves are the types. Even the stamens and carpels are proved, by the frequent occurrence of monstrosities, to have this character. The former often present the appearance of leaflets thickened at their edges by the formation of pollen; and these reproductive vesicles are themselves found, by observation of their early development, to differ but little in essential character or mode of production from any other form of cellular tissue. The carpels, moreover, are proved to be leaves, not only by such monstrosities as the one formerly mentioned, but by the fact of their bearing *ovules* at their edges; for these ovules are essentially *buds*, (as may be seen in particular abnormal instances), like those developed from the edges of various leaves, such as those of the *Malaxis paludosa* (Bog-orchis), and *Bryum calycinum* (one of the air-plants of the tropics), which are capable of developing themselves either separately or while still attached to the parent structure. The special reproductive organs of the Cryptogamia might probably be reduced to similar elements, if their monstrosities were observed; thus, the *sori* of the Ferns have been seen to be replaced by clusters of leaflets, each of them representing a metamorphosed *theca*.

Reproduction in Animals.

528. Although among the lower tribes of the Animal kingdom we may recognise the same simple and general condition of the reproductive system, as that which has been shown to exist in plants, it is in the higher classes much more completely specialised, and its relation with the nutritive system is much less obvious. This is an evident result of the peculiar complexity and heterogeneous character of the more perfect animal organisms, which prevent the employment of the mode of propagation, by mere extension of some part of the original structure, that is carried to so great an extent even in the highest plants. The only forms under which this mode of reproduction (which is but a peculiar operation of the nutritive system) manifests itself, have been already noticed (§ 514); but some additional particulars may here been mentioned. In the

gemmiparous propagation observed in many of the POLYPES, the new being is obviously nothing but an increased development of a part of the parent structure, and exactly corresponds with the bud of a plant; a similar mode of increase seems to exist in some of the simpler Entozoa, where the young sprout from the interior of the cavity of the parent, and swim about, after their separation, in its contained fluid. The *fissiparous* generation, as it is called, is evidently but another form of the same plan; the parent structure not putting out a smaller and younger bud, but dividing itself into parts of which each has the power of reproducing the whole. It is among the INFUSORIA that this mode is most characteristically seen. Thus, the Paramœcium divides itself transversely, the division at first appearing like a notch, and gradually extending itself across the body, until the halves are completely separated (Fig. 94, *a*). Some species of Vorticellæ divide themselves longitudinally in like manner (Fig. 77, *b*); and instances still more curious might be mentioned. Amongst many higher animals this mode of increase is practised, as already stated; but it is seldom that a more special reproductive apparatus is not also developed. The object of this apparatus, in animals as in plants, is to form and mature a germ, which, from the time of its first organisation, is destined to be the rudiment or embryo of a new being, and which is separated from its parent, (in the first instance at least, § 515 *note*), in a form altogether dissimilar to that which it is ultimately to assume.*

529. The different means provided in the Animal kingdom for the evolution and maturation of germs, and the early processes of development in these, will now be considered in their general aspects. As in the Vegetable kingdom, it will be found that there is throughout an essential correspondence in the function, however different its manifestations may appear. There is yet much uncertainty, however, regarding its condition in many of the lower classes of animals; and it will therefore be better to confine the present outline to the description of the principal types which may be recognised as distinct, than to attempt to define the groups to which these respectively belong. The great distinction in the character of the reproductive bodies liberated from the parent, corresponds with that already pointed out in the vegetable kingdom; for we find in the lowest classes of animals, as the SPONGES and POLYPIFERA, an evolution of

* These views regarding the essential difference between that *general* condition of the Reproductive function which is only one application of the nutritive processes, and the *special* form of it more commonly understood as such, were suggested to the author by an extended comparison of the modes of propagation in plants and animals; and he imagined himself to be unsupported in them by any other authority. He is most happy to find, however, that so eminent a physiologist as Burdach has taken the same view. This author has employed distinct terms to characterise the different types of the function, which may be best understood from their French synonymes;—*génération accrémentitielle*, or propagation by addition to the fabric of the individual, designating the first;—and *génération sécrémentitielle*, or propagation by *separate* germs, being applied to the second.—Ehrenberg also has recently expressed the opinion that the gemmiparous and fissiparous modes of reproduction are essentially the same.

gemmules, evidently analogous to the *granules* emitted by the Algæ (§ 519-20), which are formed by one set of organs only, and appear to consist of nothing but the germ of the future being, unprovided with any supply of nutriment for assisting its early growth. In the higher animals an *ovum* or egg is produced, like the *seed* of Phanerogamia, by the concurrence of two sets of organs, which are sometimes united in the same individual, (as in many Mollusca), but are more commonly separated. This ovum, however, is usually thrown off from the parent at an earlier period of the development of the embryo than the seed of plants; but a large store of nutriment is provided for it, upon which it subsists until competent to obtain its own support. Sometimes the ova are retained within the body of the parent until the young are hatched, so that they come forth alive; the animal is then said to be *ovo-viviparous*. In the true *viviparous* form of reproduction, which is confined to the MAMMALIA, the ovum is never furnished with more than a very small store of nutriment for the incipient development of the embryo; this being adapted to gain a new and peculiar attachment to the parent, which affords it a direct and continual supply.

530. The connection between the general and special modes of Reproduction is most plainly seen amongst some Animalcules, which, like the lowest Algæ, propagate themselves in a manner which may be considered either as an extension of the parent structure by budding, or as a formation of the germs of new beings not yet restricted to some one part of the fabric as in higher organisms. Thus, the *Volvox globator* (Fig. 93, *a*) produces its offspring from every part of its interior surface; these, after a time, quit their attachment, and swim about freely within the body of the parent, which finally ruptures to give them exit. Not unfrequently, however, it occurs that a third generation is seen within the second, before the escape and diffusion of the latter. This, then, exhibits the *special* function of Reproduction in its most diffused condition. It is obviously a parallel case to that of the Protococcus (§ 519) and simple Confervæ (§ 520); the reproductive cell here constituting the entire animal, so that its rupture and the death of the parent are contemporaneous; whilst, in the more complex fabrics of higher animals, the reproductive organs are so far separated from the nutritive, that their functions do not interfere.* In other species of animalcules, the *germinal granules*, as they have been termed, are liberated from some particular spot in the parent structure; and their development may be watched after their separation. It not unfrequently happens that, in their early condition, their form is so dissimilar to that which they are subsequently to assume, that they have

* The reproduction of this animal has been termed *fissiparous* by some authors, and *gemmiparous* by others. In referring it to this type, the author has been influenced by its evident affinity with that of the Protococcus; and, having shown the former to be merely the most diffused form of sporuliferous propagation in plants, he thinks that this will appear to hold a similar relation with the higher kinds of reproduction in animals.

been mistaken for distinct species. According to Burdach, the Hydra propagates itself in the same manner, in addition to the mode of reproduction formerly noticed (§ 115); germinal granules being separated from its exterior surface in the autumn, which pass the winter in a state of inactivity, and are developed in the spring. In the associated Polypes, the special reproductive apparatus for the production of these germs or gemmules, has already been noticed (§ 116). Although their receptacle has been usually termed the *ovarium*, the term is incorrectly applied to them, being appropriate only to the organ in which true ova are developed in higher animals; and from the very curious correspondence which may be seen in their structure to the *theca* of Mosses, it might not be undesirable to apply that designation to them. Several other classes of inferior animals appear to propagate themselves in a similar manner; but the limits of this type are by no means ascertained. Probably, it is common to all the Acrita and Radiata; and to the inferior Articulata and Mollusca. Sometimes the germinal bodies are evolved from special receptacles; sometimes they are dispersed through the whole structure, lying in the interstices of the different organs and tissues.

531. The peculiarity of the development of one of these germs, as distinguished from that of an ovum or egg, is exactly parallel to that which has been already noticed in the Vegetable kingdom. In the former case the bodies are homogenous, and the whole of their substance is converted, in the progress of their development, into the new animal; whilst in the latter, there is an evident distinction of parts, the germ being accompanied with a store of nutriment prepared by the parent, and the whole enveloped in one or more membranous tunics. The development of these simple germs has not yet been observed in more than a few instances. That of the Polypes has already been described (§ 116-8); and in the Sponges, whose reproduction has been attentively observed by Dr. Grant, the process is not dissimilar, though still more simple. The gemmules are here developed in the interior of the structure, and find their way into the large canals, through which they are emitted. At that time they appear like globules of gelatinous matter, presenting no trace of the cavities or canals which are subsequently formed (§ 280).

532. In all Animals which form a true ovum, whether that be fully developed within the body or not, the concurrence of two sets of organs, analogous to those described in plants, is a necessary condition; the office of one being to prepare the ovum with its nutritious store and membranous envelopes; and of the other, to communicate to that ovum a fertilising influence. What the nature of that influence is—whether to introduce the germ which has been prepared by itself, or merely to stimulate the evolution of that already contained in the ovum,—has not yet been fully ascertained. The analogy supplied by the vegetable kingdom would certainly countenance the first supposition; but this is perhaps a case in which it would be dangerous to push analogy too far. Although the

fertilising influence is usually communicated to the ova whilst yet contained in the ovarium, as in plants, there are many instances in which it is not applied until after they have been extruded from the canal which conveys them from it; this is the case in most Fishes and Batrachia, and perhaps also in some other classes. In animals whose reproduction is performed on the first plan, the ova are not unfrequently extruded in a sterile condition, if from any cause the system is in a state of activity, and the fertilising influence be withheld. In the common fowl, for instance, barren and imperfect eggs are not unfrequently laid during the whole season, if the bird be highly fed, and no fecundation take place; but this is well known to be very injurious to its health. Such eggs, though apparently the same in structure as those which have been fertilised, soon decompose, when submitted to the heat of incubation, instead of undergoing the changes accessory to the development of the embryo. This is analogous to what occurs to the seeds of plants, if the influence of the pollen be not communicated to them. In describing the ovum, and the changes it undergoes during its early development, it will be convenient to refer principally to that of Birds, pointing out what is deficient in that of inferior classes, and what is different or superadded in viviparous animals.

533. The ovum, while yet contained in the ovarium, may be termed for distinction the *ovulum.* It consists of the following parts.—1. A dense transparent membrane containing the yolk, and thence termed the *yolk-bag.*—2. The yellow fluid mass known as the *yolk.* This, at an early period is composed of an oily matter, mixed with a number of minute and transparent globules; in Reptiles and Fishes, however, these ingredients exist separately, and appear to have different functions. At a more advanced period, the yolk contains a multitude of larger globules of regular spherical form and perfect transparency; and the presence of these distinguishes the ovulum of oviparous animals, in which the store of nutriment is destined to supply the embryo with the means of its development for a considerable period, from that of the Mammalia, in which its function is speedily superseded by the new attachment that the ovum forms with the parent.—3. A layer of granules adherent to the interior surface of the yolk-bag, and apparently forming part of it. In one portion, this layer, which is elsewhere transparent, becomes thickened and opake, so as to form what has long been known as the *cicatricula* or germ-spot. The centre of this spot is, however, perfectly diaphanous, and free from any granular appearance. This is occupied by—4. The *germinal vesicle* (discovered by Purkinje), a very minute cellule, frequently not above $\frac{1}{100}$ of a line in diameter; it contains a pellucid lymph; and on one of its sides, which are formed of extremely delicate membrane, another spot has recently been detected (by Wagner) which is too minute for analysis; it is termed by him the germinal-spot (see Fig. 136).

534. The last-named parts appear to be those essential to the ovulum, and the next to be merely envelopes superadded for particular purposes. In Insects, the *germinal vesicle* and *spot* constitute the entire ovulum; and, on the other hand, in Mammalia, a new envelope is added to those that exist in birds,—namely, the *Graafian vesicle;* this, however, does not leave the ovarium, but bursts to permit the escape of the ovulum into the oviduct. It is in their early condition that the ovula of Mammalia most resemble those of Birds; since, at a subsequent period, the increased development of the yolk in the latter concurs with the other alterations connected with the mode of its future development, to produce a dissimilarity. A most important change, however, which occurs in all instances at a certain period of the evolution of the ovum, whether fertilised or not, is the rupture of the germinal vesicle, and the consolidation of the granular layer within the yolk-bag into a membrane, from which the embryo, however complicated its organs and systems may afterwards be, altogether originates. This is called the *germinal membrane*, or *blastoderma;* and at the part of it in which the vesicle lay, there still remains a transparent space or area. The ovule of Birds, on entering the oviduct, becomes encased in a secretion from its lining membrane, which is termed the *albumen*, and known as the *white of the egg.* The layers of this albumen first deposited become consolidated into a membrane, which is in close apposition, therefore, with the yolk-bag; and, when all the albumen is deposited, a similar membrane is formed around it, lining the shell that afterwards covers its surface. The complete *ovum* consists, therefore, of the shell, (which is well known to be a porous structure composed of calcareous matter cemented by animal glue), the membrane lining it and enveloping the albumen, the albumen itself, the membrane separating it from the yolk-bag, and lastly, the ovulum with its yolk and germinal membrane, in which last part important changes are now commencing. The parts are essentially the same in other oviparous Vertebrata, although somewhat differently arranged: in the Batrachia, for instance, the germinal membrane, instead of being confined to one spot, nearly envelopes the yolk; and in Reptiles, as well as Fishes, there is usually an absence or partial deficiency of calcareous deposit on the exterior. In Mammalia, the ovulum, in descending through the oviduct into the receptacle or matrix in which it is to undergo its continued development, also receives an additional envelope, the *chorion*, which afterwards performs a most important part in its new connection with the parent.

535. In the perfect eggs of the common Fowl, before incubation has commenced, the *cicatricula* is of a round form, a whitish colour, and generally about $\frac{1}{6}$ of an inch in diameter (Fig. 174). After incubation has proceeded for 7 or 8 hours, a small dark line, termed the *primitive trace*, may be seen upon it; one extremity, which is rather swollen,

corresponds nearly to the centre of the transparent area (Fig. 175). This primitive trace constitutes the first appearance of the embryo, the large extremity being the situation of the head. As incubation proceeds, the cicatricula expands, and the transparent area becomes more pellucid and defined. About the 12th or 14th hour, the germinal membrane, (still of merely granular consistence), becomes divided into two layers, termed the *serous* and *mucous*, of which the former is situated immediately under the yolk-bag, and the latter in contact with the yolk. Between these, as formerly stated (§ 320, 1) the *vascular* layer is found; but this does not exist separately until between the 20th and 24th hours, and seems to be formed by a division of the mucous layer. It is in the serous layer that the primitive trace exists: at first it occupies a long furrow, the membrane being thickened into two ridges (Fig. 137, B); about the 20th hour, this furrow is converted into a canal open at both ends, by the junction of its margins, as at C; and soon after, the larger extremity of it is closed. In this canal a semi-fluid matter is subsequently deposited, which becomes the rudiment of the spinal cord and brain. The parts of the serous layer which surround it gradually become thicker and more solid; and before the 24th hour, four or five small round opaque bodies are seen, which become the rudiments of the dorsal vertebræ.

536. Up to this period the layers of the germinal membrane have continued nearly flat and uniform; but about the 25th hour, when they cover nearly a third of the circumference of the yolk, they begin to exhibit various folds, which afterwards serve for the formation of the cavities of the body. The parts of the germinal membrane which lie beyond the extremities of the embryo are folded in so as to make a depression on the yolk; and their folded margins gradually approach one another (Fig. 138, 9) under the abdomen, which lies next the interior of the egg. The layers of the germinal membrane are bent down also towards the sides of the spinal canal (Fig. 137, D); so that there is formed under each end of the embryo a short sac or cavity, which communicates with the yolk by an opening common to both (Fig. 139, *a*). These sacs indicate the rudimentary state of the intestinal tube; the anterior corresponding to the œsophagus, the posterior to the lower part of the large intestine. At the anterior fold of the germinal membrane, a considerable space is left between the serous and mucous layers, which is occupied by a dilated portion of the vascular layer, forming the first rudiment of the heart (Fig. 139, *b*); this is seen about the 27th hour. As the subsequent development of the individual systems will have been particularly described under their respective heads, they need not be further traced here. But the changes which the remaining parts of the egg undergo must not be passed over, as they are extremely interesting and curious.

537. The Vascular Area (§ 321) is the part in which the blood appears to be formed from the subjacent yolk; and it furnishes the nutritious

fluid to the embryo by means of two principal trunks, called the *omphalo-mesenteric arteries*. The intestinal cavity, which has been seen to be, in its first formation, but a part of that in which the yolk is retained, remains continuous with it in all oviparous animals. In BIRDS, the *sac of the yolk*, (formed by the expansion of the germinal membrane within the original yolk-bag, so as to become a complete envelope,) is gradually drawn into the body of the embryo, as incubation advances; and, at the period of the exit of the chick, it is entirely contained within the abdomen. In many FISHES, however, the yolk is not taken into the embryo when it bursts its envelope, and the little fish swims about with the bag depending from the abdomen, and exposed to the contact of water, which will be presently seen to have an important influence upon it. In the MAMMALIA, on the contrary, the function of the yolk is merely temporary, being superseded by the formation of a vascular connection with the parent; its proper sac and vessels, however, are discernible at an early period; and, in the orders which most nearly approach Birds in the structure of their reproductive apparatus, this is proportionably larger; but, instead of being withdrawn into the body, its connection with the intestinal tube becomes gradually obliterated, and it remains on the umbilical cord as a small vesicle, which may be distinguished during the early period of uterine gestation.

538. But in order that the nutritious matter stored up by the parent may be converted to the nutrition of the embryo, it is necessary that it should undergo some changes in which atmospheric air is concerned, as in the germination of seeds (§ 380); and during the development of the fœtus, its blood requires aeration as much as that of the adult animal. "In the early stages of development there appears to be what may be called a General or Interstitial respiration, or a change essential to life, produced by oxygen in all the substance of the embryo, or of its accessory parts, which, as the fœtus is more perfectly formed, takes place in particular organs only. As soon as a peculiar nutritive fluid, and a central propelling organ are produced, this fluid is exposed on the expanded surface of the yolk, to the influence of the respiratory medium, either directly or through the coverings of the ovum."* It will be convenient to trace the evolution of the respiratory system of the egg, first in Fishes, and then in the higher Vertebrata. In most of the osseous fishes, the blood of the fœtus is transmitted to the vascular area, which gradually extends over the whole yolk, by a prolongation of the intestinal veins passing through the liver. It ramifies on the sac of the yolk, where it is aerated, at first through the thin membranes of the ovum, and subsequently by direct contact with the surrounding element. It then returns

* See the excellent paper, by Dr. Allen Thomson, on the development of the vascular system in the Fœtus of Vertebrated Animals, from which this section has been principally derived. Edinb. New Philos. Journal, vols. ix. and x.

to the heart by another set of vessels, which enter the vena cava. As the yolk becomes diminished in size, and the permanent respiration is established, the blood passes more directly from the liver to the heart, by the enlargement of vessels which were at first capillary into venous trunks, just as in the metamorphosis of the Batrachia (§ 311). In the cartilaginous Fishes, however, the blood sent to the respiratory surface is derived from an arterial trunk; and this is the case in all the higher Vertebrata. Most of the Fishes in this tribe, such as the Rays and Sharks, are ovo-viviparous, retaining their ova in the body for a longer or shorter time after development begins. In these, the membrane lining the oviduct of the parent is very vascular, and its blood is probably aerated by the introduction of the surrounding element into the abdominal cavity; so that the aeration of the fluids of the ovum may take place through its means. This may be regarded as a sketch of the plan which is more fully developed in viviparous Reptiles, and carried to its highest extent in Mammalia. Where the ovum is extruded at an early period of development, apertures are found in the angles of its horny covering, through which a current of water is permitted to pass over the vascular membrane.*

539. In the early period of the development of the *Batrachia*, the same means of aerating the blood are adopted as in fishes; but near the epoch of their maturity, we find the traces of another organ that is formed by an extension of the intestine near its posterior termination, which expands so as to occupy a considerable space in the abdomen; on its membranous walls (which subsequently constitute the urinary bladder of the animal), a plexus of arteries ramifies; and the blood which has passed over it, is conveyed through the liver into the vena cava. In the *Lizards* respiration is carried on by the sac of the yolk during the first half of incubation: but the vesicular membrane extended from the fœtus, which is called the *allantois*, gradually expands itself between that sac and the general envelope or chorion; and this, during the remainder of the fœtal life, serves as its aerating surface, entirely superseding the sac of the yolk, which seems to be subsequently concerned only in the absorption of nutriment. The greater part of the allantois is left in the egg when the fœtus emerges from it; and a small part of its root only remains to form the urinary bladder of the adult animal. Many Lizards and Serpents retain their ova in the oviduct, until the allantois is sufficiently expanded to carry on respiration; and, in those which are completely ovo-viviparous, such as the Viper, the allantois becomes closely united with the vascular lining of the oviduct, so as to expose the venous blood of the fœtus to the oxygenised blood of the parent. In some of the Turtles and Serpents, a large proportion of the allantois

* This is well seen in the ova of the ray and dog-fish, so common on our shores, and called by the fishermen "sea-devils" and "fairies' purses."

remains to form the urinary bladder of the adult animal; and, as it appears that water is introduced into its cavity from without, it probably serves as an auxiliary to the function of respiration during the whole of life. The respiration of the embryo of BIRDS within the egg is performed upon precisely the same plan (Fig. 176). The results of this change upon the surrounding air have been already mentioned (§ 426).

540. It now remains to state the peculiarities in the development of the ovum in MAMMALIA. Even in this class, the ovulum originally contains a yolk-bag, within which the germinal membrane expands, just as in oviparous animals; and, in passing through the oviduct, it gains an additional envelope, the chorion (§ 534). But the oviduct, instead of immediately conveying the ovum out of the body, deposits it in the receptacle provided for its further development, namely the *uterus*. During its early period of increase within this matrix, the allantois is formed, and possesses the same situation and function as in oviparous animals, being interposed between the fœtus and the enveloping chorion; and the latter being in contact with the vascular lining of the uterus, the venous blood of the fœtus is arterialised by the influence of that of the parent communicated through it. The relative sizes of the allantois, and of the sac of the yolk, or *umbilical vesicle* as it is termed in Mammalia, vary much in different orders, and are usually in an inverse proportion to one another. Thus, in the *Rodentia*, which presents many other characters of degradation, the umbilical vesicle is so large, and the allantois so little developed, that the latter is almost imbedded in the folds of the former, instead of enveloping it. In the *Carnivora*, on the other hand, the allantois almost entirely incloses the umbilical vesicle as well as the fœtus. But the allantois in Mammalia is never more than a temporary respiratory organ; for it speedily gives place to one peculiar to this class, which is elaborated out of the chorion. In the ruminating species, in which its formation may be most easily traced, it takes place in the following manner. The vessels which ramify on the outer layer of the allantois, which is in contact with the chorion, gradually prolong themselves into the latter membrane, and sprout, as it were, from its surface, so as to give it a flocculent appearance. At the same time, similar changes take place in the lining membrane of the uterus at certain points; and its processes, which are almost entirely composed of blood-vessels, interlace with those of the chorion, so that the blood of the fœtus may be submitted to the arterialising action of that of the mother. There does not appear, however, to be any more direct communication between the two vascular systems, than through the parietes of their respective vessels; but this is precisely analogous to what occurs in other organs, as in the lungs and glands. In what precise form the fœtus derives its nutriment from the parent, is not yet ascertained; but it is probably the liquor sanguines only which transudes, the red particles being formed by the fœtus

itself. The number and extent of the points of connection between the embryo and the parent differ considerably in the various orders: in the inferior tribes and in the early condition of the higher, they are diffused over a considerable portion of the chorion; in the advanced stages of the gestation of the latter, however, they are concentrated into one part, forming what is termed the *placenta*. This is composed of a spongy parenchyma, containing many cells into which the maternal blood passes by vessels prolonged from the lining of the uterus; and the vessels of the fœtus ramify minutely on the walls of the cells. This organ has therefore an evident analogy with the lungs of the perfect animal,—the maternal blood occupying the place, and performing the function, of atmospheric air. It is most interesting to observe, as we ascend the animal scale, one structure thus superseded by another, adapted to the increased extent of the function progressively required; and to compare this with the corresponding changes which take place during the fœtal development of the higher Mammalia, those structures having there a temporary office, which are the only ones concerned in the development of the lower classes.

541. In the greater number of Mammalia, the ovum is retained in the uterus until the fœtus assumes nearly the form of the adult, and is capable of maintaining its own existence, if the digestive system is supplied with appropriate nutriment. That furnished by the mammary glands (which are supplementary additions to the essential reproductive apparatus of this class), is the most appropriate, but it is not usually indispensable. In the *Marsupialia*, however, the embryo quits the uterus in a comparatively imperfect state, resembling a worm in form and appearance; and, being conveyed to the marsupium, it remains attached to the nipple, almost without motion, for a considerable period. There is still a degree of uncertainty as to the mode in which the ova of the *Ornithorhyncus* and other *Monotremata* are connected with the uterus during their stay in its cavity: but it seems probable that no placenta is formed, the general surface of the chorion acting as the aerating membrane (§ 75).

NOTE to § 517. An interesting case, in which a *Mucor* (one of the inferior FUNGI constituting *Mould*) developed itself in the form of a *Conferva* (belonging to the ALGÆ) in a fluid medium, but was subsequently recognised by its fructification, is related by Mr. Berkeley in the Magaz. of Zool. and Botan. vol. II, p. 340. The rank which this gentleman holds as a Mycologist precludes all doubt as to the genuineness of the fact.

CHAPTER XIV.

SUBORDINATE LAWS REGULATING THE EXERCISE OF THE REPRODUCTIVE FUNCTION.—DISTINCTION OF SPECIES.—PROPAGATION OF SPONTANEOUS OR ACQUIRED PECULIARITIES.

542. When we contemplate the immense number of diversified forms which the study of the organised creation brings under our notice, and witness these forms perpetuated, as it would seem, by the process of reproduction, so as to constitute distinct races, the question naturally arises whether all these had a different origin; or whether the characters of any of them have been so modified in the course of time, as to lead to the belief in the diversity of origin of those which were at first really identical. When it can be *shown* that two races have had a separate origin, they are regarded as of *different species;* and, in the absence of proof, this is *inferred* when we see some peculiarity of organisation, characteristic of each, so constantly transmitted from parent to offspring, that the one cannot be supposed to have lost, or the other to have acquired it, through any known operation of physical causes. It cannot be regarded as an unimportant question to the *naturalist* to ascertain what these constant distinctions are; whilst it is an investigation of high interest in a *physiological* point of view, to trace the modifying influence of external circumstances upon the structure and functions of living beings, and to enquire how far the result of such influences may be transmitted hereditarily, so that the difference produced by them may be perpetuated. Where races which have originally sprung from a common stock present marked differences, they are spoken of as *varieties;* and the variety may be *transient*, from its peculiarity manifesting a tendency to disappear,—or *permanent*, where it continues to be transmitted without change. The uncertainty of the limits of species is daily becoming more and more evident; and every naturalist is aware that a very large number of races are usually considered as having a distinct origin, when they are nothing more than permanent varieties of a common stock. Whilst the exertions of the enterprising discoverer are adding to our already enormous list of species, from the unexplored resources of foreign lands, the skill of the horticulturist and of the breeder is exerted to produce new varieties of species already in our catalogues: and it has unfortunately too often happened, that a new specific name has been invented for the latter as well as for the former; and that a mere hybrid or transient variety has thus taken the rank of a species, to the confusion of all true principles of arrangement. The philosophic naturalist, on the other hand, aims to reduce the number of species by investigating the degree of variation which each is liable to undergo, the forms it assumes at different periods of its existence,

the permanent characters by which it may be distinguished during its whole life, the habits which are natural to it, the degree in which these may be changed by the influence of circumstances;—and, in fine, he endeavours to become acquainted with the *whole* natural history of a reputed species, before separating it from another to which it may be closely allied.

543. Many examples may be given of the success with which this mode of investigation is now being prosecuted. The belief which is gaining ground that many diversified forms of the simpler Cryptogamia may arise from similar germs developed under different circumstances, has already been noticed (§ 65-8). The same may, perhaps, be surmised without improbability of the Infusorial Animalcules; and with respect to these, patient observation has already done much in reducing the number of species amongst the forms previously known (whilst the improved powers of the microscope have revealed many new ones), by showing that the same individual may present very diversified appearances at different times, owing to the variable distention of its digestive cavities, and the changes which it undergoes in the process of *fissiparous* reproduction (§ 528). Among the higher plants, the experiments of Mr. Herbert on the primrose, cowslip, oxslip, and polyanthus (which he proves to be all varieties of one species), are sufficient evidence of the important results which would probably accrue from a similar investigation in other quarters. In Zoology, again, the very interesting paper of Mr. Gray* may be referred to, as proving the great influence of external circumstances in modifying the form of shells; it is there shown, among other instances, that what have been regarded as *six* distinct species of *Murex* (§ 100) are in reality but different states of *one;* and Mr. Stutchbury has been equally successful in reducing the number of species of Patella, Cypræa, and Oliva, by attending to the changes of form which each individual undergoes in the progress of its development. Many instances might be related in proof of the uncertainty of reputed specific distinctions among higher classes. Insects have been seen presenting the characters of different species on the two sides of the body; and it is now certain that an erroneous multiplication of species among Birds, especially in the migrating tribes, has been occasioned by their change of plumage at different seasons. And finally, to return to the Vegetable kingdom, the uncertainty of all principles of arrangement founded upon arbitrary characters has been demonstrated by the fact recently published,† that the flowers and pseudo-bulbs of three distinct *genera* of Orchideous plants have been produced by the same individual.‡

* Philos. Transactions, 1833. † Linn. Trans. vol. xvii.

‡ This fact has also come under the author's own notice in the Durdham Down Nursery, near Bristol, two of the genera being the same as in the instance just quoted, but the third a different one, so that *four* may thus be regarded as of the same species.

544. It has been formerly stated (§ 72) that the Naturalist endeavours to simplify the acquirement and pursuit of his science, by the adoption of easily-recognised external characters as the basis of his classification; but these can only be safely employed, when indicative of peculiarities in internal structure which are found to be little subject to variation, and which are not liable to be affected by the influence of physical causes. The colour of flowers, for example, is liable to so much alteration from the influence of soil and climate, that it is seldom regarded as of itself any test of the unity or diversity of species: in moths and butterflies, on the other hand, the uniform appearance of particular spots on the wings is held sufficient to constitute a specific character, because it is never known to vary; and it would probably be found associated, if the examination were pushed far enough, with some unequivocal differences in the configuration of internal organs. Amidst all these difficulties attending the discrimination of species from structural characters alone, it is not unreasonable to enquire if there are any other means of effecting the object with greater certainty. This subject has been fully considered by Dr. Prichard in his elaborate work on the Physical History of Man; all that can be here considered are the laws regulating the intermixture of species, and the propagation of hereditary or acquired peculiarities.

545. The conclusions which have now been attained on the first of these points, and which (if stated in a sufficiently general form) are equally applicable to both the Animal and Vegetable kingdoms, may be regarded as one of the most valuable tests which naturalists possess. In plants, the stigma of the flower of one species may be fertilised with the pollen of an allied species; and, from the seeds produced, may be raised plants of an intermediate character. But these *hybrid* plauts will not long continue the race; for, although they may ripen their seed for one or two generations, they will not continue to reproduce themselves beyond the third or fourth. But, if the intervention of one of the parent species be used, its stigma being fertilised with the pollen of the hybrid, or *vice versâ*, a mixed race may be kept up for some time longer; but it will then have a manifest tendency to return to the form of the parent whose intervention has been employed. Where, on the other hand, the parents were themselves only varieties, the hybrid is only another variety, and its powers of reproduction are rather increased than diminished; so that it may continue to propagate its own race, or may be used for the production of other varieties, almost *ad infinitum*. In this way many beautiful new varieties of garden flowers have been obtained, especially among such species as have a natural tendency to change their aspect.*

* There are many instances in which foreign plants have been introduced into this country, and have received different specific names, but have been found capable of producing fertile hybrids; in these cases a more accurate examination of the original locality has generally shown that the parents were nothing more than permanent varieties, or even hybrids naturally

Amongst animals, the limits of hybridity are more narrow, since the hybrid is totally unable to continue its race with one of its own kind; and although it may be fertile with one of its parent species, the progeny will of course be nearer in character to the pure blood, and the race will ultimately merge into it.* In animals, as among plants, the mixed off-springs originating from different races within the limits of the same species, generally exceed in vigour, and in the tendency to multiply, the parent races from which they are produced, so as often to gain ground upon the older varieties, and gradually to supersede them. Thus, the mixture of the European races with the Hindoo and South American has produced tribes of such superior characters of body, and of such rapid tendency to multiplication, that there is reason to believe that they will ultimately become the dominant powers in the community.† The general principle, then, is that beings of distinct species, or descendants from stocks originally different, cannot produce a mixed race which shall possess the capability of continuing itself; whilst the union of varieties has a tendency to produce a race superior in energy and fertility to its parents.

546. In examining into the characters of the different species of Plants and Animals with which different regions on the earth's surface are peopled, the naturalist soon becomes aware that there are many kinds which are restricted to particular localities, whilst others are diffused extensively or even universally over the globe;—that there are some spots (especially insular ones), of which the aboriginal inhabitants are almost entirely different from those elsewhere found;—and yet that amongst these there will always be found species holding the same rank with regard to the remainder, and thus representing each other in different countries. Thus, the species of plants and animals originally inhabiting the eastern and western hemispheres were probably almost entirely different, until the agency of man changed their geographical distribution; and almost the same may be said of the species north and south of the Equator. On the other hand *man*, and his constant attendants the dog and the fly, exist in every quarter of the globe. Again, we find in New Holland no quadrupeds which do not belong to the order *Marsupialia* or *Monotremata* (§ 75), with the exception of a dog which is believed to have been introduced by man, and to have run wild; and none of these species are found

occurring between other varieties. This is particularly the case with many of the South American genera, such as that elegant garden flower, the Calceolaria; and this is probably the explanation of the almost indefinite number of splendid varieties, well known to horticulturists, which may be obtained from the South American Amaryllis.

* One or two instances have been mentioned in which a mule has, from union with a similar animal, produced offspring; but this is certainly the extreme limit, since no one has ever maintained that the race can be continued further than one generation, without admixture with one of the parent species.

† Several additional instances of this kind are related in Dr. Prichard's work, vol. i. p. 147 and in Mr. Combe's Constitution of Man, chapter v.

elsewhere. The greater part of the plants also belong to new genera; and those included in the genera already known constitute distinct species,—with scarcely any exception but among the Cryptogamia, the distribution of which seems more extended than that of flowering plants. The Flora of insular situations, if at a great distance from land, contains very few species which occur elsewhere. Thus, among the flowering plants of St. Helena, which is so far removed even from the western shores of Africa, there have been found, out of 61 native species, only *two* or *three* which exist in any other part of the globe. From these and many similar facts it appears fair to conclude, that every species of plant and animal had originally a distinct locality, from which it has been dispersed, according to the capabilities possessed by its structure of adapting itself to changes in its external conditions, its own locomotive powers, and the degree in which it is subject to external agencies. "What is a rare plant," says Decandolle, "but one which is so organised that it can only live in a particular locality, and which perishes in all others; such a plant is incapable of assuming different forms. What, on the other hand, is a common plant? It is one robust enough to exist in very different localities, and under very different circumstances, and which will therefore put on many different forms."* Plants, then, are liable to run into varieties in proportion as they are more robust, more common, or more cultivated; and some native species are, from this cause, domesticated with greater difficulty than many exotics. Precisely the same may be said of animals; those which have the power of adaptation to differences of temperature, food, &c. are most universally diffused; while those which can only exist within narrower limits of variation are restricted to the neighbourhood of their original locality.

547. It becomes a most interesting question, then, to determine what are the changes which may be produced by the influence of external circumstances, and how far these are hereditarily transmissible. On this subject, a few facts may be stated which will give an insight into the nature of the enquiry; but it is one which deserves more attention than it has yet received, since it is not only essential to the correctness of all Natural-history classifications, but is connected with some of the highest questions in Physiological science. One of the most obvious distinctions, where it is well marked, is that of size; and yet a little examination will show that it is one most open to fallacy. Thus, a plant only a few inches high in a poor dry soil, may become much larger in a damp rich one; and this is a very common effect of cultivation. On the other hand, by *starvation* naturally or artificially induced, plants may be dwarfed, or reduced in stature: thus, the *Dahlia* has been diminished from six feet to two; the Spruce Fir, from a lofty timber tree to a pigmy bush; and many of the trees of plains become more and more dwarf as they ascend

* Library of Useful Knowledge. Botany, p. 138.

mountains, till at length they exist as mere underwood. That a similar influence will be productive (within narrower limits, however,) of corresponding effects in the animal kingdom, no one can be ignorant; and a very curious illustration is given by Mr. Gray of the effect of external conditions upon the size of Mollusca, in the fact that there is so much difference of size between individuals of *Bulimus rosaceus* on the coast and on the mountains of Chili, that the latter have been described as distinct species. He also mentions that the *Littorina petræa* found on the sea side of Plymouth Breakwater acquires, from its superior exposure to light and heat, and probably also from the greater supply of nutriment which it obtains, twice the size which is common to individuals living on the north side within the harbour.* It is interesting to remark that these great variations occur in animals which, from their fixed condition, and the preponderance of their nutritive system, have most alliance with the vegetable kingdom; and it seems probable that a diminution of the vital stimuli, which in them only reduces the growth, would be fatal to other tribes whose animal powers are more active, and which have therefore greater means of suiting their external conditions to their bodily constitution.

548. Other modifications in the form and relative size of individual parts are very common in Vegetables, where the tissues are so simple, and the different organs so much alike in elementary constitution. Thus, cultivation often converts a single flower into a double one, by the metamorphosis of its stamens into petals, or by the development of a row of petals previously abortive, or by the change of the small tubular florets of a composite flower (like those composing the *disk* or *eye* of the Dahlia) into flat expanded florets which constitute the ray. Cultivation has a similar effect in obliterating the spines, prickles, and thorns, from the surface of many plants; a change which was fancifully, but not improperly, termed by Linnæus "the taming of wild fruits." The instances of such alterations effected by external agency in the vegetable kingdom, are almost innumerable; but it is very difficult to say how far the varieties thus created may become permanent by their hereditary transmission. The usual principle is, that propagation by seeds will only reproduce the *species*, the *race* not being continued with any certainty. In most plants which have been much altered by cultivation—such as the Apple, the Cabbage, or the Dahlia—the seeds, if dropped on a poor soil, will produce plants which approximate to the original type of the species; whilst from the seeds of the *Cerealia* (corn-grains), which are believed to have been originally grasses of some very different aspect, no other forms are ever produced which might assist in the solution of the curious problem of their origin. It is not improbable that, as among animals, varieties which arise from some peculiarity in the constitution of the being itself,

* Gray, in Philos. Trans., 1833, p. 786.

are more liable to be reproduced in the offspring, than those which are simply the result of external agencies. It is evident, at least, that here also the capability of undergoing such modifications is that which renders the species most truly valuable to man.

549. Amongst animals, the various breeds of domestic cattle, of the horse, dog, &c. afford abundant evidence of the modifying influence of external conditions; since there is no doubt that they have originated from single stocks, and that their peculiarities have been engrafted, as it were, upon their specific characters. Between the Shetland pony and the Arabian racer, for example, or between the Newfoundland dog and the Italian greyhound, there would seem much greater difference than between the Lion and Tiger (the sculls of which are so much alike that even Cuvier was not always able to distinguish them), or between various other species of the Feline tribe, which, from the incapability of domestication, have not been exposed to such influences. That these domesticated races, however different their external characters, have a common origin, is proved by the fact that, whenever they return to a state of nature,—as is the case with the dogs introduced by the Spaniards into Cuba, and the horses and wild cattle which now overspread the plains of South America, —the differences of breed disappear, and a common form is possessed by all the individuals. It is not a little curious, too, that instincts which must have remained dormant for many generations during the domesticated condition of the race, should re-appear when this change takes place in its habits; thus, among the wild horses of South America there is the same tendency to associate in herds under the protection of a leader, as among those of Asia whose ancestors have never been reduced to subjection. "It seems reasonable to conclude," as Mr. Lyell has justly remarked, "that the power bestowed on the horse, the dog, the ox, the sheep, the cat, and many species of domestic fowls, of supporting almost every climate, was given expressly to enable them to follow man throughout all parts of the globe, in order that he may obtain their services and they our protection." "Unless some animals had manifested in a wild state an aptitude to second the efforts of man, their domestication would never have been attempted. If they had all resembled the wolf, the fox, and the hyæna, the patience of the experimentalist would have been exhausted by innumerable failures before he at last succeeded in obtaining some imperfect results; so, if the first advantages derived from the cultivation of plants, had been elicited by as tedious and costly a process as that by which we now make some slight additional improvement in certain races, we should have remained to this day in ignorance of the greater number of their useful qualities."

550. How all the varieties of breeds have been produced which are now so striking, is a question much more easily asked than replied to satisfactorily. That peculiarities of structure sometimes arise independently

of external agencies can scarcely be doubted; thus, it is by no means uncommon to find individuals of the human species with six fingers and six toes; and such peculiarities are more likely to be continued hereditarily than those which have been acquired. Sometimes advantage has been taken by man of accidental varieties of this kind, for some purpose useful to him, and he has exerted his skill to perpetuate them. The following example is of comparatively recent occurrence. In the year 1791 one of the ewes on the farm of Seth Wright in the state of Massachusets, produced a male lamb, which, from the singular length of its body and the shortness of its legs, received the name of the *otter* breed. This physical conformation, incapacitating the animal from leaping fences, appeared to the farmers around so desirable that they wished it continued. Wright determined on breeding from this ram, and the first year obtained only two with the same peculiarities. The following years he obtained greater numbers; and, when they became capable of breeding with one another, a new and strongly-marked variety, before unknown to the world, was established.* This shows the influence which the circumstance of a scanty population may have formerly had in the production of varieties, both in the human and other species. At the present time, any peculiarity which may occasionally arise speedily merges by intermixture, and returns to the common standard; but it may be imagined that, in the older ages of the world, some race in which a peculiarity existed, may have been so far separated from the rest as to necessitate frequent union among its members, so that the character would be rendered still more marked instead of disappearing; and, being propagated for a few generations, would be rendered permanent. Acquired peculiarities, on the other hand, are seldom reproduced in the offspring, unless they have a relation with the natural habits and physical wants of the species; but, when this relation exists, they may be transmitted as regularly as the specific character. Thus, in dogs, the relative perfection of the organs of sight and smell, perhaps also of hearing, varies much in different breeds, and their mode of hunting their prey undergoes a corresponding change; but in these cases no new instinct is developed, the difference merely consisting in the relative proportion of those already existing; and the new peculiarities have an intimate relation to the habits of the animal in a wild state.† It is impossible not to recognise in many acquired habits,

* Phil. Trans. 1813.

† In a mongrel race of dogs employed by the inhabitants of the banks of the Magdalena almost exclusively in hunting the white-lipped Pecari, a peculiar instinct appears to have become hereditary, like that of the pointers and other dogs of this country. The address of these dogs consists in restraining their ardour, and attaching themselves to no animal in particular, but keeping the whole herd in check. Now among these dogs some are found which, the very first time they are taken to the woods, are acquainted with this mode of attack; whereas, a dog of another breed starts forward at once, is surrounded by the Pecari, and, whatever may be his strength, is destroyed in a moment. Mr. Lyell mentions that some

however, something more than a relation to the instincts necessary for the preservation of the species; they evidently arise, in part at least, from the connection of the race with man. This is more particularly exemplified in the instance of the breed of shepherds' dogs, which often display an extraordinary hereditary sagacity respecting their peculiar vocation; as well as in cases which have been frequently mentioned, where the descendants of dogs to which peculiar tricks have been taught, have displayed an unusual aptitude for learning the same. It may then be considered that the capability of undergoing such modifications, is a part of the psychical as well as structural character of the dog, even in a wild state; and that his relation to man may have as important an influence on *his* hereditary propensities, as the supply of their physical wants has on animals of other species. The same may, perhaps, be said of the horse, in the races of which we find peculiar habits transmitted from parent to offspring, which are the pure results of human instruction. It is from the want of this relation towards either the natural habits of the species or their subserviency to man, that habits acquired by other animals do not become hereditary. Thus, pigs have been taught to hunt and point game with great activity and steadiness, and other learned individuals of the same species have been taught to spell; but these acquirements have in no instance been transmitted to the offspring, not being the result of the development or modification of any instinctive propensity naturally existing. In like manner, however artificially the forms of domesticated animals may have been altered in all the individuals of successive generations, the usual character of the species and variety is maintained in each one of the offspring; unless, as sometimes happens, this alteration happens to coincide with natural varieties of the species. Thus, instances are on record in which dogs, that have been deprived of their tails by accident or design, have produced puppies with a similar deficiency; but as breeds of tail-less dogs have spontaneously arisen, there would be a stronger tendency to the perpetuation of the acquired peculiarity, than when no such peculiarity naturally occurred. It has also been asserted, however, that cats deprived of their tails will often produce one or two tail-less kittens at each birth; and that a cat which had its tail distorted by accident, has been known to transmit the deformity to some of its offspring.

Englishmen engaged in conducting the operations of the Real del Monte company in Mexico, carried out with them some greyhounds of the best breed, to hunt the hares which abound in that country. The great platform which is the scene of sport, is at an elevation of about 9000 feet above the level of the sea, and the mercury in the barometer stands habitually at the height of about 19 inches. It was found that the greyhounds could not support the fatigues of a long chase in this attenuated atmosphere; and before they could come up with their prey they lay down gasping for breath: but these same animals have produced whelps which have grown up, and are not in the least degree incommoded by the want of density in the air, but run down the hares with as much ease as the fleetest of their race in this country. Some curious instances of a similar propagation of acquired peculiarities connected with the natural habits of the race are given us by Mr. Knight, Phil. Trans. 1837.

These are certainly exceptions to the general rule, but must not be left out of view; there can be no doubt that much has yet to be learned of the influence of the state of the parent upon the development of the offspring; and that, though credulity and the love of the marvellous have been the occasion of many strange fictions being transmitted to us, we are by no means justified in rejecting the doctrine without further enquiry.*

551. Any one who takes an extensive survey of the psychical as well as corporeal peculiarities of the human race must discover that both are susceptible of a higher degree of education than those of any other tribe of animals; and it is in consequence of this, that man has surmounted the obstacles interposed by his naked and defenceless condition, and found the means of existence in every part of the globe. And in general it may be observed, that the more difficulties are presented by circumstances to the supply of his instinctive wants, the more are his intellects called into exercise for their gratification. Thus, the conditions of civilised life are more calculated to excite the dormant energies of his mind, than the pastoral habits of the Nomade tribes, scarcely now advanced beyond patriarchal simplicity, or the easily satisfied wants of the Indian hunter or the Polynesian fisherman. If, again, this power of self adaptation had been confined to the *mind* of man, whilst his body continued unable to resist changes in its external conditions, or to perform those actions which his new circumstances might require, his race must as necessarily have ceased long ago to exist, except in spots peculiarly favoured by Nature, as if, with his present organisation, he had been made dependent upon those mere instincts, which are just capable of maintaining his life when supplied by the ministration of others. The educability of man's bodily frame is in fact scarcely less remarkable than that of his psychical powers. Although each of his organs of sensation is naturally inferior in acuteness to the corresponding organ of some other animal, it may be rendered by constant practice so far superior to the usual standard as to convey a degree of information greater than that which brutes can attain. Thus, the experienced seaman announces with confidence the proximity of land, or the aspect and direction of a vessel, which the ordinary voyager cannot discern; and the watchful ear of the North American Indian distinguishes the tread of friends or foes when his civilised companion is unconscious of their neighbourhood. That these acquired powers are sometimes propagated as hereditary instincts, seems probable when we remember that, among some savage nations of North America and New Holland, precisely the same notion of *direction* is manifested, as is evinced, in a degree scarcely more remarkable, by the lower animals; individuals frequently traversing pathless forests for the first time without swerving in the least from the direct line towards the point at which they are aiming. No one, who has sufficient opportunity of observation, can doubt that the

* Montgomery on the Signs of Pregnancy, p. 16.

intellectual faculties which have been developed by cultivation, are generally transmitted to the offspring in an improved state; so that the descendant of a line of educated ancestors will probably have a much higher capacity for instruction than the child that springs from an illiterate race.

CHAPTER XV.

SENSIBLE MOTIONS OF LIVING BEINGS.

552. The power of executing movements, without the direct application of mechanical force, cannot be in itself regarded as a characteristic of the Animal kingdom; since many evidences of it are seen among Vegetables. This power must, it is obvious, depend upon a property inherent in some of the tissues of the organism, of contracting under the influence of peculiar stimuli; and there is no more difficulty in imagining a tissue to be possessed of such a property, than in acknowledging its power to separate from the circulating fluid the elements of its nutrition, and to convert them into an organised fabric. This property of *contractility* on the application of a stimulus, may be readily distinguished from the elasticity which is simply due to the mechanical relation of the particles composing the tissue; the latter being retained as long as there is no evident decomposition, whilst the former is an essentially *vital* endowment. An elastic ligament, when stretched, tends to contract only in virtue of the mechanical force which has been created in it; but a muscle which contracts upon the stimulus of a simple touch, or one of a still less mechanical nature, can do so only by a property of its own. This property is diffused, in various degrees, through a large proportion of the Vegetable as well as the Animal kingdom. It is probably possessed by all the tissues actively concerned in the nutrition and reproduction of the beings belonging to the former; and it is manifested under the influence of the vital stimuli (heat, light, moisture, &c.), as well as, in some peculiar cases, in obedience to impressions of a mechanical nature. In the lowest and simplest animals, whatever degree of contractility is possessed, appears to be almost equally diffused through the system; and we can neither discover in them any structure specially endowed with this property, nor anything resembling a nervous system fitted to call it into exercise. In proportion as we ascend the scale, however, we find a distinct muscular structure evolved, in which the general contractility of the body becomes, as it were, concentrated; and, in proportion to its development and complexity, it supersedes the corresponding but more

feeble powers of the remainder of the tissues. It is now almost entirely subjected to the nervous system; and all those parts of it, which are not connected with the functions of organic life merely, are rendered subservient to the will, and thus become the instruments of its operation upon the place and condition of the body.

553. It is among the lowest classes of Plants that some of the most curious and inexplicable motions are witnessed. Those which occur in connection with the reproductive functions have already been noticed; but there are others no less interesting. Thus, in the plants of the group of *Oscillatoriæ*, belonging to the class of ALGÆ, the filaments have a movement of alternate flexion and extension, writhing like worms in pain; sometimes they appear to twist spirally, and then to project themselves forward by straightening again. These movements are greatly influenced by temperature and other external circumstances; in heat and solar light they are more active than at a low temperature and in shade; and they are checked by any strong chemical agents, which also put a stop to the motions of the animalcules inhabiting the same water. Another group of Algæ, the *Nostochinæ*, manifests similar properties. Its members are generally composed of several distinct portions, which unite, like some of the compound animals, during a part of their existence, and afterwards separate; these have considerable power of spontaneous movement, the causes of which it is equally difficult to detect.

554. In many of the higher Plants, evident movements may be observed,—sometimes taking place in obedience to the ordinary vital stimuli, and forming part of the regular series of phenomena of growth and reproduction;—and sometimes being performed in respondence to excitement of a mechanical kind. The immediate connection of these movements with the organic functions, in the first class of instances, and the indication they would seem to give of consciousness and sensibility in the second, have led many persons to seek for an explanation of them in the fancied attribute of a nervous system. But it will be seen, if the question be fairly investigated, that, whilst no evidence of its presence is furnished by the minutest anatomical research, no argument for its operation can be deduced from the phenomena. In the simplest and most intelligible instances of sensible motions in plants, the change is the result of the contraction of the part to which the stimulus is applied. Thus, if the base of the filament of the Berberry be touched with the point of a pin, the stamen immediately bends over and touches the style. In this case, the movement is produced by the peculiar contractility of the tissue on the interior side of the filament, which, when called into operation by the application of a stimulus, necessarily occasions the flexion of the stalk. This peculiar irritability has a relation with the functions of the flower; since, when called into play (as it frequently is) by the contact of insects, the fertilisation of the stigma will be assisted. Many similar instances

might be adduced, in which a corresponding operation is connected with the process of reproduction in Plants.

555. There are cases of more complexity, however, in which an irritation of one part produces motion in a distant and apparently unconnected organ. Thus, in the *Dionæa muscipula* (Venus' fly-tray), the contact of any substance with one of the three prickles which stand upon each lobe of the leaf, will occasion the closure of the lobes together, by a change taking place in their leaf-stalk. And in the *Mimosa pudica* (sensitive plant), any irritation applied to one of the leaflets will occasion, not only its own movement towards its fellow, but the depression of the rib from which it springs; and, if the plant be healthy, a similar depression will be produced in the principal leaf-stalk, and even in the petioles of other leaves. Now, in animals, such a propagation of a stimulus would undoubtedly be effected by the nervous system; and it might be plausibly argued from analogy that it could not be performed without a similar apparatus in plants. Let it be first enquired, however, how the individual functions of the more complex and specialised structures among Vegetables are harmonised and brought into relation with one another. The whole system of the plant, it must be recollected, is *immediately* dependent upon external stimuli for its maintenance. All its vital properties are closely connected with the support of its organic life, and the continuance of its race: all its energies are directed towards these ends. Each organ possesses, to a considerable extent, an independent vitality; and each, when separated from the rest, can perform its own function, as long as the conditions essential to it are supplied. All the functions, however, are blended and harmonised in the most perfect plant by means of the *circulating* system; and, from the ordinary phenomena of vegetable nutrition, there is no reason to believe that any other bond of union exists, since they may be all referred to the vital endowments of the several parts thus brought into connection with one another.

556. Now with regard to the movements under consideration, it is beautiful to observe, that Nature, in effecting a new purpose, has accomplished it, not by adding an entirely new structure, but by modifying those already existing. The irritability of which they are the result, appears to be of precisely the same character with that just now described in the Berberry. In fact it seems but an exaltation of that common to most of the vegetable structure, which exhibits itself under various forms; thus, the leaf of the wild Lettuce exudes, when the plant is in flower, the milky juice contained in its vesicles, if these be irritated by the touch; and the contraction of the poison-gland of the Nettle, when the tubular hair which surmounts it is pressed, appears to be another manifestation of the same property. This irritability has been shown to operate upon distant parts, in the case of the Mimosa, and probably also in the Dionæa, through the circulating system. Where each leaflet

is implanted upon its rib, there is a little swelling or intumescence; this is more evident where the lateral ribs join the central one; and it is of considerable size at the base of the petiole, where it is articulated with the stem. The experiments which have been made upon its properties, have been performed, therefore, in the latter situation; but the description of their results will apply equally well to the rest. The intumescence consists of a succulent tissue, which, on the upper side, appears very distensible, and on the lower very irritable. In the usual position of the leaf or leaflet, the distension of the two sides seems equally balanced; but any means which causes an increase of fluid on the upper side, or a contraction of the vesicles on the lower, will obviously give rise to flexion of the stalk. The latter effect may be readily produced by touching that part of the intumescence itself; and then the leaf or leaflet will be depressed by the contraction of the part *immediately* irritated, just as in the case of the stamen of the Berberry. The same result follows the stimulation of this part by an electric spark, by the concentration of the sun's rays upon it with a burning glass, or by chemical agents; and if, instead of applying a temporary stimulus, whose effect is speedily recovered from, a notch be made in the lower side of the intumescence, the balance between its resistance and the expansive tendency of the upper side is then permanently destroyed, and the stalk remains depressed. Now, supposing the lower side to be in its usual condition, flexion of the stalk may result also from whatever distends the vesicles of the upper part of the intumescence; and this is the mode in which the movement is usually effected. For a stimulus applied to any part of the leaf will cause a contraction of its vesicles; and the fluid expelled from them is carried by the circulating system to the distensible portion of the intumescence belonging to each leaflet, and to that of the petiole itself. The experiments of Dutrochet have completely established that it is to the vascular system alone that this propagation of stimulus is due; and these harmonise most completely with what was previously known of the influence of this system in the vegetable economy.

557. It appears, then, that these evident motions are readily explicable on the supposition that *contractility* is a property of various tissues of plants, and that this may be excited by stimuli of a physical nature. To suppose more, would be unphilosophical because unnecessary. There are other movements, however, arising from causes which originate in the system itself, of which some notice should be taken. Such are, the folding of the flowers and drooping of the leaves, known as the *sleep* of plants. These phenomena seem due to a diminution in the activity of the vital processes by which the turgescence of the soft parts of the structure is maintained; and this diminution appears partly to result from the withdrawal of the usual stimuli, especially light, and to be in part of a periodical character. For it is found that artificial light and warmth

will cause many flowers and leaves to erect themselves for a time; and that, by proper management, the usual periods may be altogether reversed. But the phenomenon cannot be altogether explained on this principle; since there are many plants of which the flowers only expand in the night, and which must be kept in darkness to prevent them from closing. Much would seem due to the law of *periodicity*, in conformity with which living beings in general appear to be organised (§ 157); for in almost all we find some periodical cessation or diminution of all the functions, which, although modified as to its period and degree by change in external circumstances, cannot be altogether done away with. One other spontaneous vegetable motion may be instanced, as of a very inexplicable character,—that of the *Hedysarum gyrans*, a Bengalese plant. Each petiole supports three leaflets, of which the central one is large and broad, and the two lateral ones, which are situated opposite to one another, small and narrow. The position of the central leaflet appears peculiarly influenced by light: for in the daytime it is usually horizontal; by the action of strong solar light it is raised towards the stalk; whilst in the evening it bends downwards; and it is manifestly depressed if placed in the shade only for a few minutes. The small lateral leaves are in incessant motion; they describe an arch forwards towards the middle leaflet, and then another backwards towards the footstalk; and this by revolving on their articulation with the petiole. They pass over the space in 30 or 40 seconds, and then remain quiet for nearly a minute; the leaflets do not move together, but in opposite directions, one usually rising while the other is sinking; the inflexion downwards is generally performed more rapidly and uniformly than that upwards, which occasionally takes place by starts. These movements continue night and day; being slower, however, in cold nights, and more rapid in warm and moist weather. They seem less affected by mechanical or chemical stimuli than do those of any other plant; and continue for a longer time in separated parts.

558. One class of spontaneous vegetable movements has been shown by Dutrochet to be due to the action of Endosmose (§ 244) in the organs which execute them. This is particularly the case in various seed-vessels, which burst when ripe in such a manner as to eject their contents with force,—as in the instance of the *Momordica elaterium* (common squirting-cucumber.) His experiments upon the capsule of the Balsam termed *Impatiens noli-me-tangere* are particularly interesting. The valves of this capsule, when the fruit is ripe, suddenly spring from each other and curl inwards, scattering the seeds to some distance. Now an examination of the tissue of the valves shows that the outer part consists of much larger vesicles than the inner; and that the fluids contained in it are the densest. By the law of Endosmose, the fluids contained in the tissue of the interior will have a tendency to pass into the vesicles of the exterior; and it will distend them in such a manner as to produce a disposition in

that side to expand, when permitted to do so, whilst the inner side has an equal disposition to contract. This at last occurs from the separation of their edges consequent upon their ripening; and then each valve rolls inwards. If, however, the valves be placed in a fluid more dense than that contained in the exterior vesicles, such as syrup or gum-water, these will be emptied on the same principle, and the valves will become straight, or even curl outwards.

559. For the rapid and energetic movements which the purposes of animal existence require, a special tissue, the muscular, is endowed in a very high degree with the property of contractility; and provision is made in the nervous system for calling that property into exercise, either in obedience to the will, or to external stimuli acting on remote parts of the organism. It was formerly shown that muscular tissue exists in two conditions; and that the form which it presents in those parts of the apparatus of organic life, in which it is introduced for particular purposes (§ 31 & 43), is much less characteristic than that which it possesses in the locomotive or animal organs. In the former case it is excited to action, like the contractile tissue of plants, by stimuli *immediately* applied to it; thus, the movements of the alimentary tube, from the stomach downwards, are solely dependent upon the contact of its contents with the mucous membrane; and a stimulus applied to any of its fibres, excites a continous action along their course for some distance. There is no reason to believe that this automatic action is *dependent* upon nervous influence; although it cannot be doubted that it is much affected, like the nutritive processes, by the conditiou of the corporeal and mental system. It is obviously necessary that this commuuication should exist, to maintain harmony of action throughout the whole machine. The sympathetic nerve appears to be its channel; and the action of the heart is, as every one knows, peculiarly liable to be affected by variations in the state of mind or body.*

560. By the contraction of muscular fibre, in obedience to the stimulus of innervation, are produced the movements of the locomotive apparatus

* It will be perceived that the Hallerian doctrine of irritability, as a *vis insita* or independent property of muscular fibre, is here unreservedly adopted, in opposition to that which maintains that not only *contraction* is produced by the stimulus of nervous influence, but that the property of *contractility* is communicated by the operation of the nervous system. It would have been foreign to the purpose of this work to have entered upon a full discussion of this very interesting question; but it is hoped that it will appear that the doctrine here maintained is consistent with itself, and with the analogies drawn from Vegetable life, as well as with what is known of the vital endowments of other tissues. Moreover it is supported by the latest and best-conducted experiments. Thus, Dr. J. Reid has shown that the exhausted irritability of a muscle is recovered as speedily when its nerve is divided, as when it is entire, provided that its nutrition be not impaired; and Dr. Madden has ascertained, on the other hand, that narcotics acting through the nerves, destroyed their power of stimulating the muscles, long before the irritability of the muscles themselves was impaired. See 4th and 7th Reports of British Association.

by which the relation of the organism with the external world is effected; as well as those motions in the system itself which are indirectly concerned in the maintenance of the organic functions, such as those of Respiration. But the fibre, although subjected to a new and special stimulus, is not insensible to the more general one, for a mechanical or chemical application will occasion its contraction; but this change is confined to the fibre stimulated, and is not propagated by continuity as in the case just mentioned.* All the movements of the fabric in general appear, in the higher animals at least, to be strictly under the control of the will; and hence the muscles which execute them are usually termed voluntary. Those concerned in maintaining the organic functions, on the other hand, though capable of being more or less controlled and directed by the will, are not dependent upon it, and may take place in opposition to it; thus, the acts of Respiration cannot be restrained by any effort of the will, beyond a certain period (§ 591). In these cases, the nervous system appears to act simply the part of a conductor, conveying to its central organs the stimulus which its sentient extremities have received, and transmitting downwards a motor influence in respondence to it (§ 592). Now as almost every muscle in the body may be excited either by this direct stimulus, or by one acting through the will, the decision as to its voluntary or involuntary character obviously depends upon the relative frequency and force with which these two modes are brought into operation. Thus, the diaphragm is constantly being called into involuntary action, and is, comparatively, but little influenced by the will; whilst the muscles of the limbs are rarely the subjects of involuntary stimulus, and are at all other times completely under the control of volition.

* An interesting remark on this question occurs in the writings of Galen, which shows the correctness of his views on the subject of muscular action. He observes that the relation of nervous action with muscle constitutes that an *animal* organ, which, as far as its own structure and properties are concerned, is a *physical* organ only, (that is, belongs to the apparatus of organic life). As to the mechanical adaptations by which the force generated by muscular contraction is brought into such varied and advantageous operation, space forbids anything being here added to what has been already stated in the Introduction regarding the means of locomotion possessed by different classes of animals. Many interesting details on this subject will be found in Roget's Physiology, vol. i.

CHAPTER XVI.

FUNCTIONS OF THE NERVOUS SYSTEM.

561. A general view of the structure and offices of the nervous system in Animals has already been given (§ 44, 230); and it has been stated that there is no valid reason to believe that anything analogous to this system exists in Vegetables (§ 222, 554). The following chapter will, therefore, be devoted to the consideration of the principal forms which it presents in the Animal kingdom, and the Functions to which it ministers. By the nervous trunks a communication is maintained between all parts of the fabric to which they are distributed, and certain central organs, in which the changes take place that *immediately* give rise to *sensation* or *originate* motion. These centres are the parts termed the *brain* and *spinal cord* in Vertebrated animals; but they consist of several distinct organs, which are found in a separate form in the inferior classes, and are termed *ganglia*. Just as it is the function of the absorbents to convey to the centre of the circulation, from all parts of the surface or the interior of the body, the fluid which they have absorbed, is it the property of certain of the nervous fibrils to transmit to the central *sensorium* the changes produced at their extremities. Until the mind becomes conscious of these *impressions*, no sensation is produced; and, to whatever motor changes they may give rise, as long as the mind is unconcerned in them, their character is the same. We shall hereafter see (§ 594) that there is a very important class of muscular movements in the animal body, the excitement of which is quite independent of any mental influence. The nature of the sensations produced will obviously depend upon the character of the impressions propagated to the sensorium; and this is, no doubt, modified by the peculiarities in the origin of the different sensory nerves. In the skin, it would appear that the bundles of fibres which supply it subdivide and ramify most minutely, so as to form a very close and beautiful network, in which no free extremities can be detected. In the nervous expansions, however, which form the essential part of the organs of *special* sensation (§ 585), it appears that the nerve divides at once into its ultimate fibres, and that these run side by side without interlacement, each terminating in a little enlargement or *papilla*, on which the impression is probably made. Analogy would lead to the belief that similar terminal fibrils exist in the *papillæ* of the skin and tongue, which seem principally composed of vascular structure enclosing nervous twigs. The network in the substance of the skin is not formed by the inosculation of the ultimate fibres themselves, which seem never to unite; but by the separation and reunion of the larger fibres, which consist of fasciculi of those more minute.

As far as is at present known, it seems that each fibre runs a distinct course from the circumference to the central organs; and that it terminates in the grey matter which is found in all ganglia, and which may, indeed, be regarded as essentially constituting them. This principally consists of vascular structure, with which the nervous fibres are brought into peculiar connection; but what is the precise relation between them is not yet ascertained. The *motor* fibres, which originate in the same part, run towards the circumference, and convey to the muscles the influence originating in the centre. They also seem to maintain a perfect separation through their entire course; although their trunks occasionally anastomose and exchange filaments with one another. Each trunk, on reaching the muscle to which it is distributed, sends out successive branches, which run across the course of the muscular fibres, and then, bending inwards so as to form loops, return to the trunk again. Of the mode in which the sensory impressions are propagated from the circumference to the centre, and the motor stimulus from the centre to the circumference, physiologists are as yet entirely ignorant. Many have supposed that it is by a movement of the fluid which the nervous tubes contain,—an idea which derives some support from the fact that the conducting power of a nerve is destroyed by tying it, whilst it is still capable of propagating a current of electricity. Of the changes immediately concerned in the production of impressions and sensations, we are, if possible, still more ignorant, having no facts whatever on which even to build an hypothesis. What has been hitherto said refers to the division of the nervous system concerned in the reception of impressions, the production of sensations, and the stimulation of muscles to contraction; and as these are all purely animal functions, it has been called the *nervous system of animal life*. There is another set of nerves, however, which constitute what is termed the *sympathetic* or visceral system; this is distributed to the various nutritive organs, and is evidently connected with the functions of organic life, although, on the exact degree to which it participates in them, physiologists are not yet agreed. Reason will hereafter be given for the belief that it is not concerned in the sympathetic movements of the voluntary muscles, as was formerly supposed; but there can be little doubt that it is the vehicle of the sympathetic communication between the organs of nutrition, secretion, &c., and of the involuntary action of the mind upon them. This is sometimes called the *nervous system of organic life;* but we must not be misled by this expression into the belief that the organic functions are *dependent* upon its action (§ 222).

562. The group of ACRITA is regarded as comprehending those classes in which no definite nervous system can be discovered. It is

* For an account of the recent microscopical researches into the structure of the nervous system, see the Brit. and For. Med. Rev., No. xii.

generally believed, however, that, in the animals which belong to it, the nervous matter is present in a "diffused form"—that is to say, incorporated with the tissues; but it would be difficult to assign a valid reason for such a gratuitous supposition. An arrangement of this kind cannot be required to confer on the individual parts of the organism their vital properties, since these exist to as great an extent in beings which are allowed to be entirely destitute of it, namely the entire Vegetable kingdom. The simplest office of a nervous system is, as we have seen (§ 559), to establish a communication between parts specially modified to receive impressions, and others particularly adapted to respond to them. Where every portion of the body has similar endowments, there can be no object in such a communication; just as, where every part of the surface is equally capable of absorption, and every part of the tissue equally permeated by nutrient fluid, there is no necessity for a circulating system. The motions exhibited by animals of these lowest classes would seem to be scarcely less directly dependent upon external stimuli than those of plants; being, in fact, the result of the general diffusion of that exalted degree of irritability which is restricted in most plants to particular parts of the structure. Thus, the contractile tentacula of the *Hydra* close upon any object placed within their reach; but so does the fly-trap of the Dionæa; and it is not difficult to imagine that a similar mechanism may operate in both cases. At any rate there is no necessity for attributing such phenomena to a nervous system, when we can neither discover any traces of it, nor discern anything in them which cannot be accounted for in other ways. It may reasonably be asked, then, upon what ground this polype or any similar creature is regarded as belonging to the animal kingdom; and it is not easy to give a definite reply to such a question. Although, however, the greater part of the motions, not only of the individual members, but of the whole body, seem to be performed in obedience to such stimuli as govern the actions of plants, observation of the living polype will show that *all* its motions are not of this character, but that some are probably to be reckoned as voluntary, and as indicating that *consciousness* on the part of the individual, which must, in the present state of our knowledge, be regarded as a peculiar characteristic of animal existence. On the other hand, it could scarcely be proved that the movements of the *gemmules* of the Polypes and Sponges (§ 121) are of any higher character than those of the reproductive particles among the Algæ; and the employment of *cilia* for the purpose can hardly be regarded as establishing such a distinction, since the movements produced by their action are known to be involuntary in the higher animals (§ 110).

563. We have at present no certain means, it must be acknowledged, of appreciating the degree of sensibility possessed by the lowest members of the Animal kingdom. The motions which follow the impressions of external agents are our only means of judging of its possession by a parti-

cular being; and the analogies which have just been mentioned seem to indicate that, if these motions are *accompanied* by sensation, they are not *dependent* upon it. Much error has probably arisen from comparing the manifestations of life exhibited by creatures of this doubtful character, with those of the highest animals; and thence inferring the presence of a nervous system with its appropriate organs, because motions are witnessed in the former which bear some analogy to those of the latter. But, when it is considered how completely vegetative is the life of such beings, and how closely all their motions are connected with the performance of their organic functions, it would seem obvious that the general comparison should be made with plants rather than with animals; and that we should seek the assistance of principles of a higher character, only when those we already possess are insufficient to explain the phenomena. A nervous system would seem to be required only in a being possessed of a number of distinct organs, whose actions are of such a character that they cannot be brought into mutual relation, without a more immediate and direct communication than that afforded by the circulating system, which as we have seen, is the only bond of union between distant parts that plants possess. In the lowest and simplest animals, whatever degree of contractility exists, appears to be almost equally diffused through the system; and we neither find any special sensory organs, adapting one part more than another to the reception of impressions, nor do we observe any portion of the structure peculiarly endowed with the power of motion; neither can we discover anything like a nervous system fitted to receive such impressions, and to excite respondence to them in distaut parts. To use the forcible expression of Sir Gilbert Blane—"Mr. Huuter, by a happy turn of expression calls the function of the nervous system *inter-nuncial.* It is evident that some such principle must exist in the complicated system of the superior animals, in order to establish that connexion which constitutes each individual a WHOLE." But where all the parts act for themselves, there is, as we have seen, no necessity for such an inter-nuncial communication; and consequently, although when united their functions all tend towards the maintenance of the system to which they belong, they are capable of being separated from it and from each other without these functions being necessarily abolished. It is thus that we may account for the divisibility of many of the animals belonging to the group under consideration, which shows, in a remarkable degree, an affinity for the vegetable kingdom.

564. The Acrita, however, present links of transition to higher groups (§ 109); and the gradation of structure is manifested no less in the nervous system than in other organs. Thus, in the *Actinia* (§ 120) the base is traversed by nervous filaments, disposed in a radiated manner among the muscular partitions, and having small *ganglia* at intervals (Fig. 177); and thus is obviously sketched out the form in which this system appears

in the Radiated classes.* And, among the higher STERELMINTHA (§ 111), such as the *Echinorhyncus*, nervous filaments may be detected traversing the body longitudinally, and thus conducting us towards the Articulated series. In the POLYGASTRICA no connected nervous fibres have been certainly traced; but red spots may be frequently observed, which, from their resemblance to the eyes of animals a little higher in the scale, are supposed to be visual organs. This is, however, but a conjecture; since, although many of the motions of these animals are obviously influenced by light, it is impossible to say that this agent does not act upon them in the same manner as upon Plants.

565. Among the RADIATA we find these rudiments gradually assuming a more distinct and complex form. It is probable that a connected nervous system exists in all the ACALEPHÆ, although the softness of their tissues renders it difficult of detection. According to Ehrenberg, two nervous circles may be detected in the *Medusa;*—one running along the margin of the mantle, and furnished with eight ganglia, from which filaments proceed to the eight red spots which he supposes to be eyes,—whilst the other is disposed around the entrance to the stomach, and furnished with four ganglia, from which filaments proceed to the tentacula. In the *Beroe* it is stated by Dr. Grant that a nervous ring exists round the mouth, furnished with eight ganglia, from each of which a filament passes towards the other extremity of the body, while others are sent to the lips and tentacula. It must be acknowledged, however, that it is very difficult to arrive at certain conclusions as to the characters of such organs in animals whose texture is so delicate; and so many mistakes have been committed, that it would seem better to wait the results of more extended enquiry, before the exact characters of the nervous system in this class shall be decided on. In the ECHINODERMATA, however, its manifestations are much less equivocal. In the *Asterias*, for instance, we find a ring of nervous matter surrounding the mouth (Fig. 178), and sending three filaments to each of the arms; of these one seems to traverse its length, and the two others to be distributed on the cœcal prolongations of the stomach. In the species examined and figured by Tiedemann, no ganglionic enlargements of this ring seem to exist; but they are usually evident at the points where the branches diverge. In the *Echinus* the arrangement of the nervous system follows the same general plan; the filaments which diverge from the oral ring being distributed (in the absence of arms) to the complicated dental apparatus, whilst others pass along the course of the vessels to the digestive organs. This apparatus seems, therefore, to unite in itself the characters of the two nervous systems which are distinct in higher animals;

* This description and figure are given on the authority of Spix (Ann. du Musée, tom. xiii); many other observers, however, have denied that any connected nervous system exists in this animal.

one being subservient to the functions of animal life, and the other being connected with the maintenance of the several vital actions. The transition between the Radiata and Articulata, presented by the *Holothuria* and *Siponculus*, is peculiarly well marked in the nervous system of these animals; for the ring which encircles the mouth is here comparatively small, but two filaments traverse the length of their prolonged bodies, running near its abdominal surface which is their situation in the Articulated classes (§ 83, *note*).

566. It is peculiarly interesting to compare the character of the nervous system of the Radiated classes with that of higher animals of more heterogeneous structure. We here find the body consisting of a number of parts, of which each is similar to the rest; and each is connected with a distinct ganglion, that seems subservient to the functions of its own division alone, and to have little communication with the rest. This is the case, indeed, not merely with the tribes we are now considering, but with the lower vermiform species; the only difference being, that the individual portions are here disposed in a radiate manner round a common centre, whilst in the latter they are longitudinally arranged. But when the different organs are so far specialised as to be confined to distinct portions of the system, and each part consequently becomes possessed of a different structure, and is appropriated to a separate function, this repetition of parts in the nervous system no longer exists; its individual portions assume special and distinct offices; and they are brought into much closer relation to one another by means of the *commissures* or connecting fibres, which form a large part of the nervous masses in the higher animals. It is evident that, between the most simple and the most complex forms of this system, there must be a number of intermediate gradations,—each of them having a relation with the general form of the body, its structure and economy, and the specialisation of its distinct functions. This will be found, on careful examination, to be strictly the case; and yet, with a diversity of its parts, as great as exists in the conformation of any other organs, its essential character will appear to be the same throughout.

567. Among the MOLLUSCOUS classes, no repetition of parts like that just described can be said to exist; and the nervous system partakes of the general want of symmetry in the body, which seems so characteristic of the predominance of the vegetative organs in these animals (§ 138). Its ganglionic centres are principally disposed round the mouth, since its actions appear destined to little else than the supply of the digestive organs; and their size is usually proportional to the development of the organs of special sensation which are connected with them, and to the energy of the masticatory movements required for the reduction of the food. Where, however, unusually active powers of locomotion are possessed, we commonly find ganglia situated in the neighbourhood of the

organs destined to serve this purpose. From the circular arrangement of the nervous centres around the mouth, the term *cyclo-gangliate* has been applied to this form of the system; but, as this arrangement is by no means constant, the designation *hetero-gangliate*, which implies their irregular disposition, is perhaps to be preferred. In the TUNICATA, the nervous system exists under a very simple form. We find in the *Cynthia* (Fig. 83), for example, a single small ganglion, *f*, situated between the two openings of the mantle. This sends two branches which encircle the oral aperture, *a*, giving off filaments to its sensitive tentacula, and meet again beyond it; they then continue as a broad cord, *g*, along the back of the mantle, and are connected with other ganglia situated among the viscera, which seem to form part of the *sympathetic* system of nerves. In the CONCHIFERA we may trace the same general plan, but a much higher development of the nervous centres. In Fig. 179 is sketched the nervous system of a *Unio*, where are seen two quadrangular ganglia, lying above the œsophagus, and connected by a transverse fibre. From these are given off filaments to the mouth, others which run laterally to the edges of the mantle, and others that descend among the viscera, to which they give branches in their course; these last unite again to form one or two ganglia, which are always larger than the anterior masses, and which supply the whole posterior part of the animal, and the outlet of the mantle, with nervous filaments. This animal belongs to the order possessed of a double *adductor* muscle (§ 102), and exhibits more lateral symmetry than the species possessed of only one, of which the common Muscle *(Mytilus edulis)* is an example. In this animal (Fig. 180) we find two ganglia lying in proximity with the mouth, and connected by a filament which encircles the œsophagus and sometimes forms a small ganglion above it; another ganglion is occasionally formed in the same manner just beneath them. Nervous columns are sent from each lateral ganglion along the body; and these approximate in the situation of the foot, where they form another pair of ganglia, connected by a tranverse filament, and varying in size with the development of that organ, which they supply with nerves. The columns continue their separate course backwards, and again approximate in the neighbourhood of the adductor muscle, where a third pair of ganglia is situated, which is often, however, united into one mass; from this filaments proceed, which supply the muscle, the outlet of the mantle, and all the posterior parts of the body. Besides these, small ganglia have been observed on the filaments of the visceral nerves; and this system becomes more distinct from the moto-sensitive, being connected with it only at particular points.

568. As the head is not otherwise indicated, in these two classes of Mollusca, than by the position of the mouth, and does not possess any organs of special sensation, it is not to be wondered at that the ganglia connected with the œsophagus should not be larger than those of other

parts of the body, and should be even inferior in size to those more connected with powerful and active muscles. But in the higher classes it is very different; and in proportion as we meet with evidence of the possession of the senses of sight, hearing, &c., do we observe a greater concentration of the ganglionic system towards their neighbourhood. Although eyes have been asserted to exist among some of the more active Conchifera, they are not confined to any single part of the body, but are disposed along the free margins of the mantle,—an interesting intermediate condition between the diffused sensibility to light, which is probably possessed by the whole of the surface in the inferior tribes, and the concentration of the sense into one portion of it observed in other cases. Among the GASTEROPODA, two eyes only exist, and these are placed on the anterior part of the body, in the neighbourhood of the mouth. In the lower species of this class, however, the general distribution of the nervous system is not very dissimilar to that which has been last described. Thus, in the *Carinaria* (Fig. 181) we observe lobed ganglia, connected by a transverse band, lying at the sides of the œsophagus; and these send off the optic nerves and tentacular filaments. Besides other branches transmitted to the nighbouring organs, two principal trunks are sent backwards (as in the Muscle), which unite in a large ganglion situated among the viscera; from this, nerves proceed to the foot and posterior part of the trunk. A separate set of visceral filaments, connected but at one point with the symmetrical system, has also been described. In the *Bulla* (Fig. 182) however, we find the œsophageal ganglia much larger in proportion to the abdominal; and the nervous matter forms a kind of collar encircling the œsophagus, so that a considerable portion is *above* that canal, and may be regarded as approximating in character to the *brain* of higher animals. Another small ganglion is situated anteriorly to this ring; and two of considerable size, connected with the cephalic ganglia by large cords, are found in the neighbourhood of the foot. Other small ganglia are disposed among the viscera, and seem to belong to the sympathetic system. In some other species of this class, the nervous system attains a still higher grade of development; the greater part of its ganglionic centres being placed above the œsophagus, and the foot as well as the rest of the body deriving its nerves from this mass, instead of from a subordinate ganglion.

569. The nervous system of the *Cephalopoda* exhibits an obvious approach towards that of vertebrated animals, in the concentration of the cephalic ganglia into one mass, which, though still perforated by the œsophagus, lies almost entirely above it, and is sometimes protected by plates of cartilage which constitute the rudiment of a neuro-skeleton (§ 82). In the *Nautilus*, however, and other species composing the inferior order of this class, the general distribution of this system corresponds pretty closely with that seen in the higher Gasteropoda. The

œsophagus is still encircled with a ganglionic ring (Fig. 183), of which the upper part gives off the optic nerves, whilst the lower supplies the mouth and tentacula, and sends trunks backwards into the shell. The trunk which supplies the internal tentacula, and what is regarded as the olfactory organ, has a small ganglion situated upon it; and other ganglia, which probably belong to the sympathetic system, are found on the nerves distributed to the viscera. In the Cuttle-fish, and other naked species, whose habits are more active and general organization higher, we find a somewhat different arrangement (Fig. 184). The organ of vision here attains an increased development and importance; an organ of hearing evidently exists; and the whole surface of the body is possessed of sensibility. The cerebral mass, therefore, attains a much increased size, and several smaller ganglia, connected with the organs of sense, are found in its neighbourhood. The portion of the œsophageal collar that remains below the aperture for the passage of the tube is now relatively small. From it proceed outwards two large trunks which pass to the mantle, and which enter two ganglia before their final distribution. Two central trunks pass from it towards the intestines; and ganglia are found also upon the ramifications of these, which probably belong to the sympathetic system. The appearance of ganglia on the nerves that supply the mantle is evidently connected with the increased locomotive powers possessed by that organ in the order we are considering; and they are particularly evident in those in which the lateral fins are much developed. It is stated by Dr. Sharpey* that the nerves of the arms of the Cuttle-fish have a structure perfectly similar to that of the abdominal cord of the Articulata,—consisting of two pairs of trunks, one of which has ganglionic enlargments corresponding with the suckers, whilst the other passes over these without contributing to their formation. It would seem probable, from considering the origins of the cephalic nerves in this class, that the greater part of their cerebral mass is to be regarded as analogous to the optic lobes or ganglia of Vertebrata, which will be seen to constitute the largest portion of the brain in many Fishes. The infra-œsophageal part, from which the auditory and respiratory nerves arise, and which is continuous with the two large trunks distributed to the system, probably correspond with the *medulla oblongata* (§ 578). We do not perceive any part analogous to the spinal cord of Vertebrata, which is an organ possessed of independent powers distinct from those of the brain, and to which, therefore, a mere nervous trunk, however large, cannot be rightly compared. We have traced, in the Cephalopoda, the highest development of a nervous system formed to minister to the nutritive functions only; we shall now follow that of the Articulata, in which the locomotive powers are so predominant;

* Müller's Physiology, p. 676.

and we shall afterwards find that the Vertebrata combine the types characteristic of both.

570. The plan on which the nervous system is distributed in the sub-kingdom ARTICULATA exhibits a remarkable uniformity throughout all its classes; whilst its character gradually becomes more elevated as we trace it from the lowest to the highest divisions of the group. It usually consists of a double nervous cord, studded with ganglia at intervals; and the more alike the different segments, the more equal are these ganglia. The two filaments of the nervous cord are sometimes at a considerable distance from one another, and their ganglia distinct (Fig. 197) ; but more frequently they are in close apposition, and the ganglia appear single and common to both (Fig. 189). That which may be regarded as the typical conformation of the nervous system of this group is seen in Fig. 190, which shows the ganglionic cord of the *Scolopendra* (Centipede). This is shown to run from one extremity of the body to the other, and to present nearly the same proportions throughout; each ganglion is in connection with one segment, and has little to do with any others ; the two filaments of the cord diverge towards the head, to enclose the œsophagus, above which we find a pair of ganglia that receive the nerves of the eyes and antennæ. We shall find that, in the higher classes, the inequality in the formation and office of the different segments, and the increased powers of special sensation, involve a considerable change in the nervous system, which is concentrated about the head and thorax, and thus approaches that of Vertebrata. And, in the simplest Vermiform tribes, we lose all trace of ganglia, the nervous cord passing without enlargement from one extremity to the other. In all of the Articulated classes, the nervous cord *appears* to run, not along the back, as in Vertebrata, but along the abdominal surface of the body. This anomaly is explained, however, by the fact formerly mentioned (§ 83 *note*), that *all* the organs in these classes appear similarly inverted, so that they may really be regarded as in a corresponding position with those of Vertebrata, when the animal lies upon what is commonly called its back, but which is really its abdomen. This view is supported by the relative position of what are believed to be the *motor* and *sensory* portions of the nervous cord in these classes. When we examine into the structure of this column, wherever it is well developed, we find that it consists of two distinct tracts; only one of these enters the ganglia; the other passes over them (Fig. 192, B, C). The first is usually regarded as the sensory, the second as the motor column. The parts of the spinal cord in Vertebrata appropriated to these offices are so disposed, that the sensory tract lies nearest the surface of the back, and the motor column in proximity to the viscera. This corresponds with what we find in the Articulata, when the general inversion of their bodies is allowed for;

since the ganglionic portion of the cord is nearest what appears the abdominal surface of the animal, and the motor column lies upon it. Besides these tracts, however, another usually exists, which lies between the motor column and the viscera; this, too, passes over the ganglia without entering them; and its nerves, which are principally distributed to the respiratory organs, usually come off at intermediate points. The relative position of these parts is explained by Fig. 192, B, which represents a ganglionic portion of the cord viewed on the side in contact with the viscera, and shows the narrow respiratory tract lying on the motor column, and this again passing over the ganglion which belongs to the sensory portion alone; and C gives a side view of the same. Nothing precisely corresponding to this respiratory tract is found in the spinal cord of Vertebrata, since the respiratory system is not in them distributed so remarkably throughout the whole body; a portion of a large and very important nerve, the *par vagun*, which arises from the upper part of the spinal cord, and is distributed to the lungs, would seem to be its real analogue.

571. A very brief sketch of the gradual development of this system in the lower classes of ARTICULATA will be here sufficient; since it is in Insects that its chief peculiarities are manifested. In the *Strongylus*, one of the ENTOZOA, we find (Fig. 185) a single cord running from one extremity of the body to the other, but separating into two portions to encircle the orifices of the alimentary canal, This is destitute of ganglia; but it sends off slender filaments, at short intervals, which encompass the body. In the lowest ANNELIDA, such as the earth worm (Fig. 186), the nervous system is almost exactly similar, except that two distinct ganglia are found anterior to the œsophagus, from which nerves proceed to the mouth. In the ROTIFERA, notwithstanding their minuteness, a nervous system may be distinctly traced. Fig. 187 shows that of the *Hydatina*, which consists of a circle of ganglia surrounding the entrance to the alimentary canal, and giving off filaments to the powerful muscles of the jaws and to the ciliary apparatus of the wheels, and of a nervous cord that proceeds backwards to the posterior extremity of the body. In the species just mentioned, this cord is single and destitute of ganglia; but in others it is evidently double, and one or two pairs of ganglia exist upon it. In the CIRRHOPODA we find another variety in the distribution of the nervous system, the same essential type, however,—the double ganglionic cord—being retained; and it was the discovery of this conformation that first led to the suspicion that these animals should be classed with the Articulata, and not as formerly with the Mollusca. At Fig. 188 is shown the nervous system of the common Barnacle (*Anatifa*). A slender nervous ring surrounds the œsophagus, and sends filaments to the neighbouring parts, but scarcely forms a ganglion above it,—this creature being, in its fixed adult state, destitute of the eyes

and antennæ which it possessed when in the condition of free-moving Crustacea (§ 92). On the columns which traverse the body, ganglia are developed at the base of each pair of members. In the higher forms of the ANNELIDA we are led to the condition of the nervous system which has been spoken of as typical of the group of Articulata; for, whilst the soft-skinned species, in which there are neither organs of special sensation, nor distinct members for propulsion, have, like the Earthworm, scarcely any ganglionic enlargements on the nervous cord, the higher tribes, in which the division into segments becomes distinct, and in which the animal relies for locomotion more upon the action of its members than upon that of its trunk, have ganglia regularly disposed at intervals corresponding with the division into segments. This conformation is shown in Fig. 189, which is the nervous system of the *Aphrodita* (sea-mouse); where we perceive two small supra-œsophageal ganglia, corresponding with the imperfectly-developed eyes and antennæ of this animal; and a series of ganglia disposed along the cord with considerable regularity, becoming smaller and closer, however, as they approach the posterior part of the body. There is evidently but little difference, except in the relative development of the cephalic ganglia, between this system and that of the MYRIAPODA just described (Fig. 190). Whilst the symmetrical system is thus attaining an increased development, traces of the sympathetic or visceral system present themselves, in the form of nervous filaments embracing the dorsal vessel, and lying among the viscera; and these are occasionally found to be possessed of minute ganglia.

572. The nervous system of INSECTS, like the rest of their organs, presents very different aspects at the different stages of their metamorphosis; and these have a peculiarly interesting relation with the general characters and habits of the animals. The *Larva* or caterpillar, it has been formerly stated (§ 86), may be regarded as, in almost every respect, on a level with the higher Annelida; all its segments are equal, or nearly so; all are usually provided with legs, and alike concerned in the function of locomotion; and its nervous cords, with their ganglia, are consequently disposed with great uniformity. The number of segments being always 13 (including the head as one), that of the ganglia is usually the same. The cephalic ganglia, placed in front of the œsophagus, are small in proportion to the size they subsequently attain (Figs. 191 and 194), in conformity with the low development of the organs of special sensation. The first ganglion of the trunk, placed immediately beneath the head, sends nerves to the first pair of legs; and all the others are similar to it. In the *Sphinx ligustri* (privet-hawk-moth), whose nervous system is represented in these figures, the two last ganglia are consolidated into one, as frequently happens.* Throughout the whole column of the larva, the

* See Newport in Phil. Trans., 1832 and 1834.

separation of its lateral halves is evident; and this is a character peculiar to the lower articulated tribes; for, in the perfect Insects, Crustacea, &c., its divisions approximate so closely as to leave no space between them. The small respiratory filaments are seen to come off a little above the ganglionic nerves, and these are distributed to the stigmata, and to the muscles concerned in respiration, whilst the others ramify on the general surface and supply the locomotive organs. Besides these systems, however, another may be detected, which appears to have its analogy in Vertebrata. At Fig. 191, A, is an enlarged representation of the cephalic ganglia and œsophageal ring of the larva of the Sphinx; and two filaments are shown to proceed from the lower side of these ganglia, and to meet in a small central ganglion from which a nervous trunk proceeds. This trunk passes downwards along the œsophagus and stomach, on the walls of which its branches are distributed; and it appears to correspond with the portion of the par vagum which has a similar distribution in Vertebrata. In the latter sub-kingdom, the par vagum supplies the lungs and heart as well as the stomach; but it is not surprising that the extended character of the respiratory organs in Insects should have occasioned the amplification of the part of the nervous system appropriated to it, into what is apparently a distinct portion of the apparatus. Besides this, we observe two small ganglia connected with nerves which come off on the side of the cephalic ganglia, and these appear to belong to the true sympathetic or visceral system, which here becomes connected with the sensori-motor nerves, sends filaments to the organs of sense, and communicates with the respiratory nerves, just as in Vertebrated animals.

573. When the larva is about to assume the *Pupa* state, a very remarkable series of changes takes place in the nervous system, the result of which is shown in Fig. 192. The ganglia are rapidly approximated, in accordance with the sudden diminution in the length of the body; but the cords themselves are not yet shortened, so that they assume a sinuous form, and, in the thoracic region, the lateral halves are more widely separated than before. No great change is yet seen in the ganglia themselves; but the œsophageal ring is much contracted; and the filaments proceeding to the rudimentary wings, which now make their appearance, begin to attain a considerable size. At Fig. 192, A, is an enlarged representation of a portion of the thoracic column, showing the transverse or respiratory nerve lying on the median line (whilst the sensori-motor cords diverge), and sending off its lateral branches between the ganglia. The *Sphinx ligustri* remains for several months in the Pupa state; and the progressive changes in its nervous system may, therefore, be very advantageously watched. It appears that, between the time of the first and that of its second metamorphosis, very considerable changes gradually take place, which all tend towards its final development. At Fig. 193 is represented what may be regarded as its characteristic form

in the pupa state. It is seen that the inter-ganglionic cords have now adapted themselves to the shortened dimensions of the body, and that they lie straight as in the larva. The cephalic ganglia are shown to have greatly increased in size, and to be in such close proximity with the first ganglion of the trunk, that the œsophageal aperture is now much contracted. The second and third ganglia of the trunk, from which the nerves pass to the wings, are considerably enlarged; whilst the fourth and fifth have coalesced into one mass, to which the sixth also closely approximates. The abdominal columns are but little altered; their ganglia, however, are now somewhat smaller in proportion to the rest.

574. The condition of the nervous system in the *Imago* or perfect insect is shown in Fig. 194. The cephalic ganglia have now undergone an enormous increase in development, the part connected with the eyes being particularly enlarged; and they extend over the œsophageal canal so much as to conceal it, uniting themselves closely with the first ganglion of the trunk. The second ganglion has entirely shifted its position and receded towards the middle of the thorax; the third has quite disappeared, seeming to have coalesced in part with the second, and in part with the one below it, as well as with their connecting cords. The next ganglion seems to contain the nervous matter,—not only of the fourth and fifth, which have evidently coalesced to form it,—but of the sixth and seventh, which have become obliterated, though their nerves are still given off from the cord. The remaining ganglia have undergone but little change.*

575. We see, then, that the tendency of the metamorphosis is to concentrate the ganglionic portion of the nervous system in the head and thorax; the former being the position of the organs of special sensation, the latter the situation of the locomotive system. A lateral concentration may be frequently observed, as well as a longitudinal one; for in some larvæ the two cords are quite distinct, and are separated by a considerable interval; and these approximate in the Imago into a single column. There are many Insects in which the concentration is carried much farther than in the instance now described; the abdominal ganglia being almost entirely obliterated, and the nervous centres restricted to the head and thorax. This is partly the case in the *Melolontha* (cock-chaffer), whose nervous system is represented in Fig. 195. The cephalic ganglia

* The origins of the nerves supplying both pairs of wings have here united; and the same structure is found in the Bee and other *Hymenoptera* remarkable for rapid flight. On the other hand, in many Insects which are not remarkable for velocity or equability of motion, the nerves supplying each wing originate separately, and have little communication, just as in the larva of the Sphinx; and in the *Coleoptera*, in which the upper pair, or *elytra* (§ 89, *note*), are motionless during flight, the nerves frequently remain entirely separate. Hence it is not unfairly argued by Mr. Newport that this common origin of the nerves is subservient to the uniformity and equability of the actions of the wings required in Insects of rapid and powerful flight.

are here seen to have great lateral development, and to approximate closely to the first ganglion of the trunk. The small lateral ganglia, also, which belong to the sympathetic nerve, are considerably developed. Three contiguous ganglionic masses exist in the thorax, from which nerves radiate to the wings and legs, and others pass backwards into the abdomen, where no ganglia exist. The greatest concentration exists, however, in the orders *Homoptera* and *Hemiptera*. In Fig. 196 is shown the thoracic portion of the nervous system of the *Ranatra linearis*, a species of the former tribe allied to the common *Notonecta* or boat-fly; and it is here seen that, besides the first, or infra-œsophageal ganglion, there is but one nervous centre in the trunk, from which filaments are sent to the whole body.

576. The CRUSTACEA present us with nearly as great a variety in the forms of the nervous system as do the Insect tribes. In some of the least-developed species of this class, the nervous filaments are scarcely perceptible. In many more, in which the equality of the segments of the body indicates an affinity with the class Myriapoda, the nervous system almost exactly resembles that of the Centipede or higher Annelida. This is the case in the *Talitrus locusta* (sand-hopper) whose nervous system is represented in Fig. 197. The two cords are seen to be at an unusual distance from one another, and even the ganglia are widely separated, although connected by a transverse filament. The cephalic ganglia are but little larger than the rest, which are very uniform in size and position. In higher orders, however, we perceive, as in Insects, a tendency to the concentration of the ganglia in the thorax, and to the increase in the size of those representing the brain. This is seen in the Lobster, where, although none of the ganglia are obliterated, the last seven are small in comparison with the first five. But it is in the short-bodied Crabs that this concentration becomes most apparent. We here find, as in some Insects, but one thoracic mass, from which the whole of the trunk is supplied with nerves, as in the *Maia squamado*, Fig. 198; and this conformation evidently leads us towards the Mollusca, in which there is a similar tendency to the concentration of the nervous matter around the œsophagus. The distribution of the nervous system in the ARACHNIDA is not dissimilar to that of the Crustacea—the Spiders of the sea. In the long-bodied *Scorpions* there is a large mass surrounding the œsophagus, formed by the union of the cephalic with the first thoracic or infra-œsophageal ganglion, from which the nerves of the five pairs of legs are given off; and, posteriorly to this, are seven small ganglia disposed at regular intervals along the trunk. In the *Spiders* (Fig. 199), on the other hand, we find the cephalic ganglia distinct, but small; and these communicate with a large star-shaped mass in the front of the thorax, which appears to be formed by the union of at least four pairs of ganglia, and which sends off nerves to the legs; from this proceeds a double cord

which swells, at its termination, into an enlargement that gives off branches to the other organs.

577. The principal varieties in the distribution of the nervous apparatus in the Invertebrated classes having now been described, we are prepared to enter upon the consideration of its conformation in VERTEBRATA. It has been already remarked (§ 139) that, in this division of the Animal kingdom, the locomotive system of the Articulated classes may be regarded as united with the nutritive apparatus of the Mollusca; and this union is nowhere more remarkable than in the nervous system. We have traced in the latter group a circle of ganglia surrounding the œsophagus, specially connected with the organs of sense, and, therefore, with the function of nutrition; we have seen these becoming, in the higher species, almost supra-œsophageal; and the nervous cords which proceed from them conduct their influence to every part of the body, no other ganglia but those of the visceral system being developed, except where extraordinary locomotive powers exist. In the Articulata, on the other hand, we have seen that the ganglia connected with the organs of special sensation and surrounding the œsophagus, are usually quite subordinate to those connected with the locomotive apparatus, in the neighbourhood of which the greatest concentration takes place; and that where this is diffused (as in the Annelida, Myriapoda, and larvæ of Insects) throughout the whole body, each segment appears much more dependent upon its own ganglion, than upon any influence it derives from the cephalic mass, whose function is probably to harmonise and direct the actions of all. Now, in the Vertebrata we find both these types of structure united; for the cerebral mass obviously corresponds with that of the higher Cephalopoda (the lowest Fishes scarcely exhibiting any advance in its character); whilst the spinal cord, being possessed of independent powers, must be regarded as something very different from a mere bundle of nerves, such as passes off from the cerebral mass in the Mollusca, and will be shown to correspond with the ganglionic cord of the Articulata. In tracing the development of the nervous system from the lowest to the highest forms it assumes in this division of the Animal kingdom, it is necessary, for the right understanding of its character, to lay aside all preconceived notions derived from the study of the human brain alone; since the extraordinary difference in the proportions of its parts, from those which we meet with elsewhere, would otherwise be a source of great confusion.

578. That which may be regarded as the most essential part of the nervous system in Vertebrata is the nervous cord commonly known as the *spinal marrow*, with its continuation in the cranium as far as its junction with the hemispheres of the brain (termed the *medulla oblongata*); this is altogether called the *cerebro-spinal axis*. With it all the nerves are connected;—the sensory nerves terminating in it, and the motor

nerves passing out from it. A ganglionic enlargement is always found in the neighbourhood of the junction of the sensory nerves with this cord,—sometimes on the column itself (Fig. 200), and sometimes on the nerves near their roots (Fig. 212). Those in connection with the nerves of special sensation, namely the optic and olfactory ganglia, are particularly large in many of the lower Vertebrata; and they constitute the principal part of what is there known as the brain. Two distinct tracts may be discovered in this column, connected with the distinct functions of motion and sensation. All the nerves which minister to these functions conjointly, have roots arising from both columns, as shown in Fig. 212; and on the sensory roots of the spinal nerves, there is a ganglionic enlargement, in which the motor portion has no concern.* The *motor* column of the spinal cord is usually spoken of as the *anterior* one, from its position in man; and the *sensory* column as the *posterior*. The former is in proximity with the viscera, whilst the latter is nearest the dorsal surface; these evidently corresponding with the position of the two portions of the ganglionic column of the Articulata (§ 570.)

579. The portions of the nervous system which seem to be peculiar to the Vertebrated classes are the *cerebral lobes* or *hemispheres*, and the *cerebellum*. The former (*b*, Figs. 200-219) constitute the mass of the brain in the Mammalia; but in Fishes they are usually inferior in size to the optic ganglia, *c*. As we ascend from the lowest to the highest Vertebrated animals, do we observe an increased development of these organs with respect to the cerebro-spinal axis and the nerves and ganglia appertaining to it, which seems to bear a pretty close relation to the degree of intelligence of the animal; their surface becomes convoluted (Fig. 211) so as to augment the quantity of cortical or grey matter; and the complexity of the arrangement of the fibres of the medullary or white portion greatly increases. The cerebral lobes are connected with both tracts of the spinal cord; and, from the points of union, fibres may be seen diverging towards all parts of their surface. The *Cerebellum* (*d*, Figs. 200-219), which is always situated beneath the hemispheres, is an organ of whose precise functions we are obliged to confess our ignorance; in the lowest classes it forms a single mass placed on the

* The nerves arising from the spinal portion of the cerebro-spinal axis have all double roots; but those of special sensation, which take their origin within the skull, are not incorporated with any motor trunk; and the motor nerves of the eye, and of the greater part of the face, are not united with any sensory filaments. The loss of the sensibility, or of the capability of motion, of particular organs, may be produced, therefore, by dividing the sensory or motor roots of their nerves, if these arise from the spine, or by dividing their distinct trunks, if their function be single; and disease or injury of these parts produces corresponding effects. Cases of palsy of the face, in which the sensibility is retained whilst the muscular power is lost, or in which muscular power is retained and sensibility lost, are by no means rare; but instances of the same affection of parts of the trunk are not so common, since any affection of a nerve in its course will here implicate both the motor and sensory filaments, which can only be separately acted on at their origins.

median plane; whilst, in the higher, it is divided into two hemispheres. It is connected with both columns of the spinal cord; and experiment leads to the belief that its office is in part to combine the individual actions of different members into the complex and nicely-balanced movements required for progression of various kinds. We may now briefly glance at the relative development and position of these parts in the different classes of Vertebrata.

580. In FISHES, although the head is generally large in proportion to the trunk, and its cavity capacious, only a small part of it is filled with the brain, which as yet appears but a slightly-developed prolongation of the spinal cord. The interval between the walls of the skull and the surface of the brain is filled with fluid contained in a closed serous membrane, the *arachnoid*.* The most anterior of the ganglia contained in the head are those connected with the *olfactory* nerves (*a*, *a*, Fig. 200); these are sometimes separated by peduncles from the rest of the brain, especially in cartilaginous fishes, such as the Ray (*a*, *a*, Fig. 202). Behind these are the *hemispheres* of the brain *b*, *b*, which are usually small in proportion to other parts; they have no ventricles or cavities in their interior, nor convolutions on their surface. We next come to the *optic lobes* or ganglia, *c*, *c*, which are not unfrequently larger than the hemispheres; these may be regarded as analogous to the principal part of the cephalic ganglia in Invertebrated animals; but, in the higher classes, they will be seen to diminish in proportion to the development of the hemispheres. Even in the more powerful cartilaginous Fish, such as the sharks, the hemispheres are already so far prolonged backwards as partly to conceal them. Behind these we find the *cerebellum*, *d*, which is but a simple transverse band in the lowest cyclostome fishes, and bears but a small proportion to the optic lobes in the Conger (Fig. 201) and others of that tribe; whilst, in the muscular Rays and Sharks, it is prolonged forwards so as partly to cover the optic lobes, and backwards on the spinal cord. Still, however, it is only the central portion which is yet developed, the hemispheres being entirely absent. The spinal cord differs much in its proportions in different tribes of this class. In the Eel and other Vermiform fishes, it is of nearly uniform size throughout; and, in the lowest of these, the cerebral ganglia are scarcely more prominent upon it than those of the leech or caterpillar. In proportion as distinct locomotive members are developed, do we find enlargements of the spinal cord corresponding with the origins of their nerves, just as in the ganglionic column of Insects; and where the

* This is one of the many instances in which a condition which is the result of disease in man is found to be the natural state of some of the inferior tribes. Amongst other cases of the same kind, the adhesion of the heart to the pericardium, and the dilatation of the air-cells of the lungs might be instanced; the former being the natural condition in Fishes, and the latter in Reptiles.

anterior members are very powerful, as in the *Trigla* (gurnard), these enlargements have an evidently ganglionic character (Fig. 200). According to Mr. Owen, they are connected with sensory organs of peculiar character, superadded to the pectoral fins. In such species as the *Lophius* (frog-fish), in which the nutritive system is enormously developed at the expense of activity of locomotion, and the animal thus constructed more upon the Molluscous type, the nervous centres are confined to the neighbourhood of the head; for the true spinal cord soon separates into a bundle of nerves which act only as conductors. Throughout the whole of the spinal column in Fishes, there is a canal which marks its division into two lateral halves, as in the Articulata; and this canal is particularly wide beneath the cerebellum,—the position in which the œsophagus passes through it in Insects, &c.,—but is contracted in the higher classes into the *fourth ventricle.*

581. In REPTILES (Figs. 203-5) we observe a considerable advance in the development of the hemispheric ganglia, and proportional diminution of those connected merely with the sensory nerves. The former contain hollows or ventricles within, into which their enveloping membrane is continued, and which, therefore, increase the general extent of surface. The cerebellum is still a simple mass but slightly developed in respect to the hemispheres. The nervous system of *Batrachia*, like all their other organs, presents, in the tadpole state, the characters of that of fishes; and these are partly retained by the perennibranchiate species during the whole of their existence. In Fig. 218, are shown the brain and spinal cord of a young tadpole; where the cerebral hemispheres, *b*, *b*, are shown to be of small size, and to be separated by a considerable interval from the optic ganglia, *c*, *c*; whilst the cerebellum, *d*, is but a transverse band, and the spinal cord narrow, although slightly dilated in parts. As the members are formed, however, and the whole condition advances, the posterior and middle portions of the spinal cord, from which their nerves are derived, enlarge considerably (Fig 219); at the same time this column is shortened relatively to the length of the body, being withdrawn from the tail which formerly contained it; and the development of the cerebral hemispheres proceeds, until, in the adult frog, the parts of the brain have the proportions represented in Fig 204. (The olfactory ganglia, which are here small, are not shown in the figure, being concealed by the hemispheres, in apposition with whose under surface they lie). In BIRDS we find the centres of the nervous system attaining a greatly-increased lateral development, and filling up the whole of the cavity which contains them. It is in the cerebral hemispheres that the principal increase is manifested; and these extend not only laterally, but so far backwards as nearly to cover the optic lobes (Fig. 210), which, as well as the olfactory ganglia, are proportionably reduced in size. The cerebellum now exhibits a considerably increased

development, especially in birds of powerful flight, and those which remain long on the wing; and we find not only a central mass, but rudiments of lateral portions or hemispheres. Still the surface of the brain is unmarked by convolutions; and the distribution of its fibres is very simple. In this class, however, we first meet with the rudiments of the great transverse commissure (*corpus callosum*), a band of fibres which unites the two hemispheres of the cerebrum.

582. The same general course of development may be observed in the different orders of MAMMALIA. The size of the cerebral hemispheres increases in every direction, so that they completely cover the olfactive and optic ganglia, which are now comparatively minute,* and often partly conceal the cerebellum, which has also attained a great increase in development, and is possessed of hemispheres in addition to its central mass. The surface of the brain is now marked by convolutions, which increase in number and in depth as we ascend from the lowest to the highest orders; being almost absent in the *Monotremata* and *Rodentia*, and but shallow in the *Cetacea* and *Ruminantia*, whilst they are strongly marked in the *Carnivora* and *Quadrumana*, and most of all in man. The internal arrangement of the fibres of the hemispheres also gradually becomes more complex; for, besides those which ascend from the sensory columns to the convolutions, and the corresponding ones which descend to the motor columns, there are others which establish the communication between the two hemispheres, and another set, again, (which is the most complex of all) that brings the different parts of the same hemisphere into connection with one another. It is in the development of the last-named set of fibres that the brain of man is so superior to that of all other animals; since there are several in which it is larger relatively to the bulk of the body. In this respect, again, we may trace the gradual ascent in the character of the organ through the different orders of Vertebrata; for the brains of *Rodentia* and *Marsupialia* are nearly as destitute of these uniting tracts or *commissures*, as are those of Birds. The spinal cord, like all other parts of the nervous system, is larger in proportion to the bulk of the animal, than in other classes; but it is much smaller in reference to the brain. Its extension through the vertebral column, and the degree of its enlargement where the nerves for the members are given off, vary, as in other cases, with the character and development of the different locomotive organs. Nothing has been yet said of the development of the *Sympathetic* or visceral system of nerves in the Vertebrated classes. This advances, however, *pari passu* with the cerebro-spinal; and in Mammalia

* The former is known in man as the bulbous expansion of the first pair of nerves, that lies upon the cribriform plate of the æthmoid bone. In reality, however, the *nerves* commence from this ganglion, the trunk which connects it with the brain being analogous to the peduncle seen in the cartilaginous fishes. The optic ganglia are known in man as the *corpora quadrigemina*.

it becomes a system of great complexity, having two large ganglia (the semilunar) in the abdomen, from which filaments are distributed to all the digestive organs, and a regular series along the spine. It communicates with each of the spinal nerves near their roots, as well as with most of the cerebral; and is believed to interchange filaments with them. It forms a plexus which is minutely distributed upon the large vascular trunks, and which probably accompanies their ramifications into every part of the system.

583. A brief sketch will now be given of the embryonic development of the nervous system in Birds and Mammalia, for the purpose of showing that the same remarkable correspondence exists in this, which has been demonstrated in former instances; and, were fuller details here admissible, the correspondence would be still more evident. It must be recollected, however, that, in all comparisons of this kind, we are not to look for similarity in external form or size, but in the grade of development, and the relative condition of different parts. The first appearance of nervous matter in the embryo of the chick, is a simple white line, running along the primitive trace (§ 535), and thus evidently analogous to the filamentous cord in the lower Annelida and Entozoa. At the 21st hour of incubation, this cord is seen to be double (Fig. 206), as in the higher Articulata; and the lower part begins to be enclosed in the rudiments of vertebræ. The slight curves at its upper part indicate the situation where the cerebral vesicles are subsequently to appear. The formation of these is seen commencing in Fig. 207, which represents the nervous system at the 40th hour; and their more advanced condition at the third day is shown in Fig. 208. Here we perceive the rudiments of the cerebellum, the large optic lobes, the small hemispheres, and the olfactory ganglia, disposed in one line, as in Fishes. The advanced condition of the brain on the 14th day, when it has nearly assumed its permanent form, is shown in Fig. 209. The early formation of the nervous system in the Mammalia probably follows much the same plan; but there are obvious difficulties in the way of becoming minutely acquainted with it. At Fig. 213 is shown the aspect of the nervous centres in the human embryo at the 7th week of development; at Fig. 214, the same at 9 weeks; and at Fig. 215, the same at 12 weeks. Although none of these bear any great external resemblance to the figures formerly given, a careful examination shows that they may be regarded as analogous to the brains of different tribes of Fishes. The fourth ventricle (§ 580), is seen to be still open, as in many of that class. At Fig. 216 is shown the brain of a fœtus of 14 or 15 weeks, which bears a general correspondence with that of Reptiles; the cerebral hemispheres being enlarged, and partly covering the optic lobes, while the cerebellum is still in a single mass, and the fourth ventricle scarcely closed. Finally, at Fig. 217 is given a side view of the brain of a human embryo of 27 weeks, in which the cerebral lobes

are seen to have wrapped themselves round the optic ganglia, and the cerebellum to have gained lateral development as well as a furrowed surface. Slight depressions, indicative of commencing convolutions, are seen on the surface of the cerebrum; and, altogether, this condition of the brain much resembles that which is permanent in the Rodentia. The occurrence of monstrosities, in which the central organs of the nervous system have been deficient while the nervous trunks have been distributed as usual, shows that the formation of the latter is quite independent of the former, just as the formation of the capillaries is independent of the heart (§ 321). And Mr. Newport's observations on the progressive appearance of the nerves supplying the wings of Insects, during their metamorphoses, also lead to the conclusion that the development of the trunks proceeds from the circumference towards the centre.

584. To enter into any detail on the functions of the nervous system would be inconsistent with the plan of the present work; and all that can here be given is a very general sketch of the different classes of actions in which it is concerned. It must be recollected that most of our knowledge on this subject is derived from the observation of its functions in man; and that we are unable to reason, except by analogy, as to the phenomena presented by the lower animals. And so difficult is it to arrive at any certainty regarding the changes concerned in these phenomena, that it is even now a disputed question whether particular motions, which may be excited by stimulating parts of the surface in animals whose brain has been removed, and which at first sight *appear* to indicate consciousness and will, are or are not independent of sensation. We may consider the functions of the nervous system under the following heads. 1. Its reception of external *impressions*, and communication of them to the sensorium, where they give rise to *sensations*. 2. The origination in the nervous centres, and the propagation along the motor trunks, of an influence which stimulates muscles to contraction. 3. The operations of the mind, which are excited by sensations, and which, to produce any action upon the corporeal system, must terminate in giving rise to a motor impulse. 4. The establishment of a connection between the organic functions, by which they are brought into harmony with one another, and influenced by certain mental conditions.

585. The reception of external* impressions is effected by the nerves termed *sensory;* the ramifications of which are minutely distributed upon all parts of the surface of the body. What is the nature of the change produced in them, by which the impression is conducted along their cords to the nervous centres, we can only guess at; but we know that such a process takes place, since division of the cord prevents any impression

* The term *external* is here employed in the usual metaphysical sense, implying that which does not originate in the *mind*. The impression may be produced by some change in the corporeal structure itself, as well as by the phenomena of the external world.

made upon its extremities from being felt; and mechanical irritation of the divided extremity that is in connection with the brain, gives rise to a sensation, which is referred to the part of the body to which the trunk is distributed. The sensation of *tact* is commonly spoken of as *general;* since the capability of exciting it is possessed by the whole surface in man, and probably also in all but the very lowest classes. The sensations of *sight*, *hearing*, *smell*, and *taste*, are designated as *special*, being occasioned only by impressions made upon particular organs, which are adapted to receive them and *them only*.* These organs we find progressively evolved as we ascend the animal scale; but though we have reason to believe that the sensations to which they respectively minister, can only be excited in a perfect form where they exist, there is good reason to believe that animals destitute of them have a diffused sensibility to the agents which excite them,—being, for example, conscious of the influence of light, although not able to see objects. This, then, may be regarded as one of the many instances in which a special structure is elaborated out of one more general. Although all the sensory nerves terminate in the cerebro-spinal axis of Vertebrata, there would seem good reason to believe that, as long as the impression which they convey is confined to that organ, it cannot produce *sensation*, (even although it may excite motions, (§ 591), until transmitted to the cerebral hemispheres.† Of the nature of the change by which the mind is rendered conscious of the impression conveyed by the nerves, we are as ignorant as of that concerned in the impression itself.

586. The next division of the functions of the nervous system is that concerned in the production of motion. As in the former case a stimulus originating in the circumference of the body was propagated towards the centre, we here find an influence excited in the centre, either by mental action or some other change, transmitted to the circumference, and this operating on the muscles, by exciting them to contraction. It has been already stated (§ 559) that these organs appear possessed of the property of contractility, which may be called into action by stimuli of various kinds; and that nervous agency is one means (and, in the living body, the principal means) by which their contraction may be produced. That the influence of the will in causing muscular contraction is conveyed by the motor trunks, is at once demonstrated by the interruption occasioned by the division of the nerve; and mechanical irritation of the cut extremity of the part which supplies the muscles, is followed by their contraction. It has been frequently supposed that the influence thus propagated is of an electrical kind, since this agent is capable of imitating it;—muscular

* The sense of taste, however, may probably be regarded as a refined kind of touch.

† Many eminent physiologists still hold a contrary doctrine, imagining that, when the brain is removed, sensibility exists in the spinal cord. For a full discussion of this question, and of the doctrine of excited actions, see the Brit. and For. Med. Rev. vol. v. p. 486, *et seq.*

contractions being produced by a galvanic current transmitted along the motor nerves. It may be objected to this doctrine, however, that other stimuli besides galvanism are capable of occasioning muscular contraction when applied to the nerves; that no unequivocal manifestation of electricity has ever been produced by *nerves* along which the motor influence is being powerfully transmitted (as evidenced by the muscular contractions it excites); and that many of the conditions of the operation of the two agents are so dissimilar that their *identity* seems scarcely admissible.* The motor influence seems really to issue from the cerebro-spinal axis, which gives rise to all the motor nerves; but, when excited by the will, it probably originates in the cerebral hemispheres. It may, however, be produced quite independently of the will, and without any influence from the brain, in modes that will presently be explained (§ 590).

587. The complexity of the operations of the *mind*, and the impossibility of deriving, from the study of the lower animals, any assistance which can be relied upon in their analogies, have hitherto been a complete bar to the successful investigation of them as a portion of the functions of the nervous system. It is yet quite uncertain how far mental acts are dependent on or connected with any changes in its condition; and we only know that they can neither be excited in the first place, nor effect any change upon the material structure of the body, except through its intervention. All acts of thought are either immediately or remotely dependent upon sensations; and, if all their inlets were closed from the first, the mind would remain dormant, like the seed buried deep in the earth. The activity of the mind is just as much the consequence of external impressions by which its faculties are called into play, as is the life of the body the result of the excitement of its several vital properties by external stimuli; and just as many animals are capable of retaining a certain degree not only of vitality but of vital action, when deprived for a time of these stimuli, (as in hybernation), so could the mind which had once been roused retain its powers by the recall of its former sensations, though debarred from the excitement of new ones.

588. The acts of mind in which the *intellectual* faculties are concerned can only produce an influence on the corporeal structure, by an exertion of the will, which, being propagated from the brain to the cerebro-spinal axis, excites in it a motor impulse that is propagated to the muscles. But various mental operations are independent of the employment of the intellect, and can produce an influence on the motor nerves by some channel distinct from the will. Of this kind are the *emotional* actions, which, though aroused by sensations, are independent of the will, and often strongly opposed to it. It is only when the emotions are strongly excited, however, that the actions performed in obedience to them have this character; if less vehement, or partially subdued by the

* See Alison's Physiology, p. 117.

will, the excited emotion merely stimulates the intellectual processes to the formation of a desire (of which it then becomes an element), and from this an act of volition results. The distinctness of the channels of emotional and volitional actions is beautifully evinced by the occasional effects of disease; for cases have occurred in which muscles have been entirely paralysed to the influence of one, and have yet been susceptible of the other. In the well-regulated mind of man, in which the passions, emotions, and propensities, (which are all conditions of an analogous nature, varying in the degree in which they are connected with the operations of the intellect, or with the performance of the organic functions), are kept under due control, few of the actions will be of this involuntary nature; but, in proportion as they predominate, whether in health or disease, the individual loses his freedom of will, and his actions approach towards an instinctive character.

589. Putting aside, then, the actions in which intellect and volition are concerned, and of whose nature we must be, for the present, content to acknowledge our ignorance, we may next enquire into the causes and conditions of the other movements which we witness in the animal body, and which,—as we trace in all of them *a direct respondence to an external stimulus*, unmodified by the will of the individual, and not directed by him towards a definite end,—may be included under the general term *instinctive*. These will be seen to predominate greatly in the lower classes of animals; and to be, indeed, in many instances, almost the only actions manifested by them; and, whilst in man they are rendered partly subordinate to his powerful reason, they display themselves in full force during childhood, or when the mind is weakened by disease. But it will be desirable to analyse these more closely.

590. In the lowest and simplest class of excited movements, the nervous system would not appear to be concerned. They result from stimuli directly applied to the muscle; and are evidently of the same character with the motions of plants. Of this kind are the motions of the heart, and of the alimentary tube below the stomach, in the higher animals; and probably, as already shown (§ 562), the greater part of the movements of the Hydra and other creatures of equal simplicity, in which no connected nervous system can be traced. They are all immediately connected with the functions of organic life, (to suspend which, even for a short time, would be fatal); and they are incapable of being controlled, directed, or antagonised by the will. Some of them are influenced, however, by mental emotions, &c., probably through the sympathetic nerve (§ 595).

591. In the next class of excited movements, the nervous system appears to act the part of a *conductor* of stimuli from the spot on which the impression is made, to the muscles which are to be called into action. These require for their performance the integrity of the *nervous circle;*

that is, of the sensory nerves which receive the impression, of the portion of the central organ (the cerebro-spinal axis) to which it is conveyed, of the portion from which the motor trunk originates, and of that trunk itself. We are quite ignorant of the cause why certain motions should be always excited by certain impressions; but it is well to bear in mind that most frequently the sensory nerves, which convey the stimulus to the central axis, enter it in pretty close proximity with the motor trunks, through which the movements are excited. In the spinal nerves, indeed, the two systems united in the same cord are often alone concerned; so that a single segment of the spinal column is all that is wanted to complete the circle, and movements may be excited in the part of the body which it supplies, when all the rest of the column has been removed. This is the case, to even a more striking degree, in the Articulata; for each segment which contains a ganglion will, in such a creature as the Centipede, continue to execute regular movements for some time. But it may be easily proved that no *direct* communication between the sensory and motor filaments is concerned in producing them, by destroying the portion of the spinal cord with which these are connected; when they will no longer be excited.

592. The movements of this class may seem but remotely connected with the maintenance of the functions of organic life; but they are essential to its continuance in all save the lowest animals. Those concerned in Respiration will afford an apposite illustration. They are excited by a stimulus, originating in the lungs (being occasioned by the presence of venous blood in the pulmonary vessels), and conveyed by a sensory nerve (a portion of the *par vagum*) to the upper part of the spinal cord. A part of the motor nerves concerned in stimulating the respiratory muscles to action arise in the neighbourhood; others are given off lower down; but to all is the motor influence equally transmitted, and this as well without the brain as with it. If the circle be anywhere interrupted, however, the respiratory movements will cease, and the aeration of the blood will be consequently checked, although no mechanical impediment exist to the entrance of air or blood into the lungs. Many other actions of the same kind are constantly involved in ministering to the organic functions, although not *immediately* essential to them; of this kind is the process of *swallowing* formerly described (§ 263). Others, again, are for the protection of the body from injury; as when the pupil contracts, from the influence of light on the retina; or when a limb is withdrawn from a flame suddenly applied to its surface. These movements are generally capable of being, for a time at least, restrained or antagonised by the will; but they cannot be altogether controlled by it. In the greater number of cases, *sensation* is produced by the impression which excites them; and hence it has been supposed to be a necessary link in the chain of actions. If it be true, however, that no impression can produce

sensation, unless it be propagated to the cerebral hemispheres (or whatever part corresponds with them in Invertebrata), it is evident that sensation cannot be *necessary* to their performance, since they will all take place when the brain has been removed. It is obviously difficult to prove that sensations do not exist in animals on which experiments are made, and whose movements would appear to indicate them; but the question seems decided by the occurrence of cases of disease in man, in which movements of limbs, that were quite insensible and palsied to the will, have been excited by stimuli applied to them; and in which the pupil has been excited to contraction by the stimulus of light upon the retina, of which the mind was not conscious. This class includes all the movements that have been termed *sympathetic*, and a part of those commonly called instinctive. A very interesting example of them is the act of sucking in the infant, which appears to be directly excited by the contact of the nipple with the lips, without the consciousness of the individual being necessarily involved; for instances have occurred in which it has been energetically performed by infants born without brain; and a similar result has followed the removal of the brain of puppies. A large proportion of the movements of the Articulated tribes, which are so uniform as to forbid the idea of judgment and will being concerned in them, probably possess a similar character.*

593. The highest class of excited movements is that in which sensations do partake, although still without the operation of the judgment or will. In these, the organs of special sense are chiefly concerned; and the actions in question appear to have a tendency to the preservation of the system and the perpetuation of the race. Of this class, the involuntary movements directed towards the acquirement of food, the construction of habitations, the balancing of the body, &c., seem to be examples; but few of these are involuntary in man; and the inference that they are instinctive in the lower animals principally rests upon the uniformity of their occurrence, especially when contrasted with the variability of those which depend upon reasoning processes. Still we find that, even in man, there are many motions destined to the preservation of the body from danger, which have been wisely rendered independent of his uncertain and capricious will. Thus, in one of the cases formerly alluded to (§ 588), the eyelids, which could not be moved by the will of the individual, closed involuntarily on the sudden approach of a body towards the eye, or on the application of a strong light. The instincts which minister to the supply of the organic functions are, in adult man, rendered subservient to volition, by which they are controlled, and to which they act as a stimulus. It is easy to perceive the final cause for this change. If the organisation of the human system had been adapted to perform all the actions necessary for the continued maintenance of

* See, on this subject the Brit. and For. Med. Rev. loc. cit.

its existence, with the same certainty and freedom from a voluntary effort as we perceive where pure instinct is the governing principle, and if all his sensations had given rise to intuitive perceptions, instead of those perceptions being acquired by the exercise of his mind, it is evident that external circumstances could have created no stimulus to the improvement of his intellectual powers, and that the strength of his instinctive propensities would have diminished the freedom of his moral agency. Although, therefore, to all the actions *immediately* necessary for the maintenance of his own existence, and for the continuance of his race, a powerful instinct strongly impels him, these propensities could not be gratified, if the means were not provided by the exercise of the mental powers, which he enjoys in a degree far exceeding those of any other terrestrial being.

594. In tracing the progressive complication of the psychical manifestations during the early life of the human being, a remarkable correspondence may be observed with the gradual increase in mental endowments which is to be remarked in ascending the Animal scale. The first actions of an infant are evidently of a purely instinctive character, and are directed solely to the supply of its physical wants; they are thus analogous to those of the lowest animals possessed of a nervous system, which are entirely governed by instinct. The new sensations which are constantly being excited by surrounding objects, call into exercise the dormant powers of mind; perceptions are formed, and notions thus acquired of the character and position of external objects; and the simple processes of association, with its concomitant—memory, are actively engaged during the first months of an infant's life. At the same time an attachment to persons and places begins to manifest itself. All these are the characteristics of the great majority of the lower Vertebrata, as far, at least, as our knowledge of their springs of action enables us to form a judgment. As the infant advances in age, the powers of observation are strengthened; the perceptions become more complete; those powers of reflection are called out which prompt him to reason upon the causes of what he observes, and to perform actions resulting from more complicated mental processes than those which guide the infant; and, at the same time, we observe the development of the moral feelings, but these are manifested only towards beings who are the objects of sense. Among the more sagacious quadrupeds, it is easy to discover instances of reasoning as close and prolonged as that which usually takes place in early childhood; and the attachment of the dog to man is evidenly influenced by moral feelings of which the latter is the object. "Man," it was expressively said by Burns, "is the God of the dog." Up to this point, then, we observe nothing peculiar in the character of man; and it is only when his higher intellectual and moral endowments begin to manifest themselves, especially those relating to

an invisible Being, that we can point to any obvious distinction between the immortal ψυχη of man, and the transitory πνευμα of the brutes that perish. May we not regard *these* as *here* existing but as the germs or rudiments of those higher and more exalted faculties, which the human mind shall possess, when purified from the dross of earthly passions, and enlarged into the comprehension of the whole scheme of Creation, the soul of man shall reflect, without shade or diminution, the full effulgence of the Love and Power of its Maker?

595. One more function of the nervous system still remains to be considered; namely, its influence on the organic processes. This has already been generally pointed out (§ 222, 368). Although there is not sufficient evidence to warrant the belief that either the processes of nutrition and secretion, or the motions of the heart and alimentary canal, are *dependent* upon the nervous system, there is no doubt that they are greatly influenced through its medium by conditions of the body or mind; and the sympathetic or *asymmetrical* system, whose branches accompany the blood vessels throughout the whole body, besides being abundantly distributed to the heart and abdominal viscera, seems to be the channel of their operation. All the sympathies between the actions of the organs concerned in the Vital functions are probably effected through its medium. Of this kind are the acceleration of the heart's action when a local inflammation occurs in a distant part, the secretion of milk about the time of parturition, and the formation of other secretions for the protection of exposed surfaces.* Whatever be the precise nature of the actions of these nerves, it is quite certain that they are not, in their natural state, subservient to sensation; and that the very slight motions which the muscles they supply may be sometimes excited to perform by irritating them, may be fairly attributed to the cerebro-spinal filaments they contain. The latter seem, however, to receive an influence from certain involuntary states of mind, particularly those of an emotional character, by which the organic functions are modified (§ 368).

* It is remarkable that palsy of the cerebro-spinal nerves supplying some parts should check the protective secretion, and thus occasion inflammation. This is the case not only in the eye, of which the outer membrane is, in the healthy state, acutely sensible to any unusual stimulus, but in the bladder, of which the lining membrane does not seem sensible unless diseased. It must be supposed to be by an influence communicated through these to the sympathetic, that the secretion is stimulated in the natural state; and it may perhaps be transmitted through those filaments derived from the sympathetic, which every cerebro-spinal nerve contains; whilst the acute sensibility of some parts when diseased, to which none but sympathetic nerves are distributed, may be accounted for by the presence of cerebro-spinal filaments in them (Müller's Physiology, pp. 668-672).

CHAPTER XVII.

ON THE EVIDENCES OF DESIGN PRESENTED BY THE STRUCTURE OF ORGANISED BEINGS.

596. If little has been expressly said upon this subject in the foregoing pages, it is because it has been thought that when the perfect adaptation that exists between all the minute details of each member of the animated world, and the harmony of the parts they have to perform in the grand system of the Universe, were being explained and demonstrated, it might be safely left to the mind of the reader to draw those inferences, which it is perhaps impossible for any soundly-judging person to avoid making, who is unwarped by the pride of human reason, or by that tendency to practical disregard of them, which, in so many instances, is mistaken by the individual himself for a valid argument on the side of disbelief. When we consider the universality of this adaptation, so constant that it cannot be the effect of chance,—the beautiful harmony of the details, uninterrupted by the slightest discordance,—and the consummate perfection of the whole, so complete as to forbid the idea of a limited power,—it seems scarcely possible to arrive at any other rational conclusion, than that the Universe with all that it contains is the work of one Almighty and Benevolent Creator.

597. Much has been said and written on the study of *final causes* in Physiology, or the examination of the particular uses of each organ, and its adaptation to the objects of the system of which it forms a part. No doubt can be entertained that, when the belief in Universal Design is once established, its pursuit into particular instances may often lead to enquiries which would otherwise have been neglected, and may put us on the right track in the conduct of those enquiries. Thus, Harvey states himself to have been excited to his researches on the movement of the blood, which terminated in the splendid discovery of its double circulation, by the contemplation of the valves in the veins; and Sir C. Bell was led to his discoveries on the functions of different portions of the nervous system, by a feeling of curiosity as to the object of the double roots of the spinal nerves. But we are not to rest satisfied with the obvious purpose of a particular structure as affording us the supposed *reason* for which it was created. As well might we think it (to take Bacon's examples) a sufficient account of the clouds that they are for watering the earth, or "that the solidness of the earth is for the station and mansion of living creatures." "The physical philosopher," says Mr. Whewell,* "has it for his business to trace clouds to the laws of evaporation and condensation;

* Bridgwater Treatise, p. 353.

and to determine the magnitude and mode of action of the forces of cohesion and crystallisation by which the materials of the earth are made solid and firm. This he does, making no use of the notion of final causes; *and it is precisely because he has thus established theories independently of any assumption of an end, that the end, when after all it returns upon him and cannot be evaded, becomes an irresistible evidence of an intelligent Legislator.*"

598. The philosophic Physiologist, who is not deterred by the clamour of bigotry and prejudice, will follow precisely the same course. The adaptation which he discovers in particular instances may well serve both to awaken his curiosity, and to lead him to suspect a pre-existing Design. But he will obtain a much more elevated view of the nature of Creative Power, if he carry his enquiries farther. He must disregard for a time, as in physical philosophy, the immediate *purposes* of the adaptations which he witnesses; and must consider these adaptations as themselves but the *results* or *ends* of the general laws for which he should search. The observation of the facts upon which he establishes these laws may have been suggested, and the phenomena themselves brought to light, by the perception of this harmony and adaptation in individual cases; but instances in which it is apparently deficient may be as valuable to him, when considered in this point of view. What, for example, would have been the present state of the science of Vegetable Morphology, which explains the metamorphoses of the organs composing the flower (§ 54), if the philosophic botanist had adopted the final cause or function of the different parts as his guide in investigating the laws of their structure, instead of tracing that structure through all its regular and irregular forms with a total disregard of their function? In considering the laws of the organised world, we have abundant opportunities of observing how diversified, both in their forms and uses, are the various types which the same rudiments may present; and that, even when undeveloped, such rudiments appear as the necessary result of these laws, and assist man in the attainment and comprehension of them. It is evident, then, that we are not to judge of the value of facts in Physiology by their immediate and obvious bearing upon the phenomena of Vital Action; for those which would seem to be of the most trifling consequence, if viewed in this light only, are often found, when properly applied, to possess an unexpected and momentous import. They are like the marks in the forest by which the American Indian at once detects the passage of friends or foes. A broken twig, a torn leaf, a flattened blade of grass, are signs which an ordinary traveller would pass without observation; but, to the practised eye of the denizen of the woods, they are alike certain and expressive. In proportion to our attainment of the generalisations to which we are thus led, we acquire fresh proofs of the Omnipotence of Creative skill. For, at every successive step, are we able to

comprehend new relations between facts that previously seemed confused and insulated, new objects for what at first seemed destitute of utility; and in the same proportion will the contemplative spirit be led to appreciate the vastness of that Designing Mind, which, in originally ordaining the laws of the animated world, could produce such harmony and adaptation amongst their innumerable results. To use another very forcible expression of Mr. Whewell's (which *he* applies, however, only to physical science, regarding Physiology as excluded from it) "the notion of design and end is transferred by the researches of science, not from the domain of our knowledge to that of our ignorance, but merely from the region of facts to that of laws."

599. To avoid all chance of being misunderstood in these views, it may not be useless to adduce, in illustration of them, one of the most obvious and simple adaptations everywhere presented in the structure of Animals,—that of the muscles to the skeleton. We constantly find in pursuing our anatomical enquiries, that, for the advantageous attachment of muscles to bones, some particular form of the latter is provided; and that, where much power or a particular direction is required, a considerable prominence is given to the point of attachment. The teleologist, who rests satisfied with the evident object of this adaptation as a sufficient reason for its occurrence, would say with truth that each of the bony processes was intended for the attachment of a muscle; and he might safely rest upon this intention as a ground for inferring the form and direction of certain muscles of extinct animals, from the prominences which are found upon their fossilized bones. He might go further, and maintain that the formation of this prominence is occasioned by the existence of the muscle; and might allege, in support of his view, the well known fact, that the osseous points of attachment are strongly developed in those persons who have much exercised their muscular system. On the other hand, the philosophic anatomist, fully acknowledging the adaptation between the osseous and muscular systems, would disregard it for the time, whilst seeking for the laws regulating the development of these systems; which laws he would aim to deduce from the observation of all the forms of each, both normal and abnormal, imperfect and complete. Thus, he would find that almost every one of the important processes in the human skeleton exists as a separate bone in some of the inferior animals; and that the complicated muscular system of man gradually simplifies itself in proportion as the skeleton exhibits more repetition of similar parts, and is, in consequence, adapted to a less diversity of actions. Supposing, then, that the physiologist has succeeded in establishing such laws independently of any assumption of an end "that end, when after all it returns upon him, becomes an irresistible evidence of an intelligent Legislator." For it may be safely left to the judgment of any candid and reflecting person, whether it does not imply a far higher degree of Creative

Wisdom and Power to suppose that, in the establishment of the laws of osteology and myology (themselves probably subordinate to some higher generalisation), all the results of each were foreseen and harmonised, so that every muscle, developed in accordance with the laws of *its* system, should find an attachment in the osseous process resulting from the action of the laws of *its* system,—than to imagine that the formation and adaptation of each separate muscle, and of each individual process, required a distinct effort of creative skill.

600. It has been one object of the foregoing pages to show that *vital* properties are as essentially connected with certain forms of matter, as are those usually denominatd *physical* with matter under its more common aspects. One more question yet remains. It is possible that the physical and vital properties of matter, which are at present our ultimate facts or axioms, may be included within a more general expression common to both? On this subject we can only speculate; but the probability appears decidedly in the affirmative. It has already been remarked that the rapid progress of generalisation in the physical sciences renders it probable that, ere long, a single formula shall comprehend all the phenomena of the inorganic world (§ 141); and it is not, perhaps, too much to hope for a corresponding simplification in the laws of the organised creation, although its progress is necessarily retarded by the many obstacles which the nature of the subject presents to the philosophic enquirer. Every step which we take in the progress of generalisation, increases our admiration of the beauty of the adaptation, and the harmony of the action, of the laws we discover; and it is in this beauty and harmony that the contemplative mind delights to recognise the wisdom and beneficence of the Divine Author of the Universe. This, in fact, is one of the highest results to which the exercise of our intellectual faculties should lead; and we cannot but believe that the Creator, in endowing us with these faculties, intended that they should conduct us nearer to the conception of his Infinite mind. But, at the same time, the vastness of the prospect thus disclosed can scarcely fail to impress us with the most humbling consciousness of our own insignificance.

601. If, then, we can conceive that the same Almighty *fiat* which created matter out of nothing, impressed upon it one simple law which should regulate the association of its masses into systems of almost illimitable extent, controlling their movements, fixing the times of the commencement and cessation of each world, and balancing against each other the perturbing influences to which its own actions give rise,—should be the cause, not only of the general uniformity, but of the particular variety of their conditions, governing the changes in the form and structure of each individual globe protracted through an existence of countless centuries, and adjusting the alternation of "seasons and times, and months and years,"—should people all these worlds with living beings

of endless diversity of nature, providing for their support, their happiness, their mutual reliance, ordaining their constant decay and succession, not merely as individuals but as races, and adapting them in every minute particular to the conditions of their dwelling,—and should harmonise and blend together all the innumerable multitude of these actions, making their very perturbations sources of new powers;—when our knowledge is sufficiently advanced to comprehend these things, then shall we be led to a far higher and nobler conception of the Divine Mind than we have at present the means of forming. But, even then, how infinitely short of the reality will be any view that our limited comprehension can attain, seeing, as we ever must in this life, "as through a glass, darkly;"—how much will remain to be revealed to us in that glorious future, when the Light of Truth shall burst upon us in unclouded lustre, but when our mortal vision shall be purified and strengthened so as to sustain its dazzling brilliancy.

EXPLANATION OF THE PLATES.

N.B. When no paragraph is referred to, the one last named is understood.

PLATE I.

Vegetable Tissues.

FIG.

1. Membranous cellular tissue, § 23.
2. Cubical and prismatical cellular tissue.
3. Muriform tissue of medullary rays § 23, 51, 286.
4. Tubular form of the same, from a fossil wood.
5. Fibrous cellular tissue, from *Orchideous* plant, § 23.
6. Dotted cellular tissue from the same,—*a*, showing merely dots,—*b*, exhibiting traces of spiral fibre.
7. Section of a duct from fossil wood, showing remains of partitions, § 24.
8. Dotted duct formed by aggregation of dotted cells.
9. Simple duct formed, in like manner, from simple cells.
10. Woody fibres clustered in a bundle, § 25.
11. Glandular woody fibre of coniferous wood.
12. Spiral vessel with single fibre, § 26.
13. Spiral vessel of *Nepenthes* with quadruple coil.
14. Spiral fibres drawn out of the vessels.
15. Annular duct, exhibiting remains of spiral fibre, § 27.
16. Close spiral duct, showing interstices between adhesion of spiral fibre, § 28.
17. Reticulated duct, § 29.
18. Dotted duct formed on the type of the vascular system.

Animal Structures.

19. Tracheæ of Insects, § 26, 395.
20. Spiral cartilage from trachea of Dugong, § 27.
21. Dilated Air-sacs of *Bombus terristris*, Humble-Bee, § 28, 396.
22. Appearance of the membrane lining Air-sacs, § 28.
23. Bronchial tubes of human lung, § 29.
24. Arrangement of fibres in tendon, with muscular fibre, § 37.
25. Arrangement of fibres in elastic tissue of *ligamentum nuchæ*.
26. Single muscular fibre from voluntary muscle, § 42.
27. Muscular structure of organic life, not united into fibres, § 43.
28. Varicose nerve tubes of the brain, § 44.
29. Cylindrical tubuli of nervous fibres.

Vegetable Structures.

30. Horizontal and vertical sections of an *Exogenous* stem of 3 years growth; *a*, pith; *b, b*, spiral vessels constituting medullary sheath; *c, c*, dotted ducts; *d, d*, woody fibre; *e, e*, bark, § 51.
31. Horizontal and vertical sections of an *Endogenous* stem; *a, a*, cellular tissue; *b, b*, spiral vessels; *c, c*, ducts; *d, d*, woody fibre, § 52.

PLATE II.

32. Seed of *Monocotyledon* (Scirpus supinus); *a*, embryo; *b*, albumen, § 50.

FIG.
33. Germination of ditto; *a*, plumula; *b*, cotyledon; *c*, radicle.
34. Seed of *Dicotyledon* (Bean); *a*, *a*, cotyledons; *b*, plumula; *c*, radicle.
35. Germination of ditto.
36. Vertical section of Fossil wood, crossing direction of Medullary Rays; *a*, dotted duct, with remains of partitions; *b*, *b*, woody fibres; *c*, *c*, cut ends of Medullary rays, § 51.
37. Different forms of leaves exhibiting the same character of *venation*, § 53.
38. Forms of anthers; *a*, lily; *b*, lemna; *c*, potato; *d*, berberry; *e*, ginger; *f*, sage, § 55.
39. Pistil of *Coriaria myrtifolia*, showing distinct carpels and styles.
40. Carpel of double Cherry; *a*, natural form, and section showing position of ovules; *b*, monstrous form of ditto.
41. Section of pistil of *Vaccinium amœnum*; *a*, calyx; *b*, ovarium; *c*, style; *d*, stigma.
42. Section of ovarium of *Thamnea uniflora*; *a*, calyx; *b*, ovarium.
43. Transverse section of ovarium of *Viola tricolor* (heartsease).
44. Flower of *Rafflesia Arnoldi*, § 58.
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48. Fronds of *Ophioglossum* (adder's-tongue); *a*, sterile or leafy; *b*, fertile or sporuliferous.
49. Theca, &c. of *Moss*; *a*, theca; *b*, operculum; *c*, peristome; *d*, columella, § 60.
50. Gemmæ of *Marchantia*; *a*, early state; *b*, commencing to form roots, § 61, 180.
51. Advanced bud, self-inverted, with stomata above, and roots below, § 180.
52. Section of Stoma and air-chamber of *Marchantia*; *a*, rings of cells, § 429.
53. Pelta of *Marchantia*, bearing thecæ associated at their bases, § 61; *a*, *b*, *c*, early development of the spores, § 523.
54. Stem and branches of *Nitella flexilis*, § 62.
55. Diagram of circulation in ditto; A, imaginary transverse section of tube; B, globules in circulation; C, the same adherent, § 353.
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70. Similar section of leaf of *Oleander*; *a*, *a*, upper cuticle possessing three rows of vesicles; *e*, *c*, chambers in lower cuticle, lined with hairs, § 428,9.
71. Vertical section of stoma of *Iris*; *a*, *a*, green cells bounding orifice; *b*, *b*, cells of parenchyma; *c*, air-chamber.
72. View of ditto from above; *a*, *a*, cells of the stoma; *c*, opening between them.
73. Similar view of stoma of *Apple*; *a*, *a*, cells of the stoma; *b*, *b*, cells of the cuticle; *c*, opening of the stoma.
74. Involucrum of *Marsilea* laid open; *a*, *a*, smaller reproductive bodies, thecæ, or anthers; *b*, *b*, larger ones, or ovules, § 524.
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PLATE III.

Animal Structures.

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80. Clio borealis, § 98.
81. Pileopsis, § 99.
82. Magilus; *a*, young state of the same.
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84. Pyrosoma; § 104.
85. Shell of Echinus; A, portion enlarged; *a*, tubercular plates; *b*, ambulacral plates, § 106.
86. Echinodermata; A, Spatangus; B, Clypeaster; C, Asterias, § 170.
87. Pentacrinus Europæus.
88. Holothuria.
89. Medusa aurita, § 108.
90. Beroe pileus; *a*, *a*, ciliated tentacula; *b*, mouth; *c*, orifice of intestine.
91. Trichina spiralis, § 111.
92. Enchelis pupa, showing alimentary canal, § 114.
93. Monas termo; *a*, Volvox globator, § 268, 530.
94. Paramœcium aurelia; *a*, the same dividing, § 114, 268 *n*, 528.
95. Hydra viridis, and H. fusca, in different states, § 115.
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110. Stomach of Ruminating Quadruped (Sheep) laid open; *a*, paunch; *b*, honeycomb stomach; *c*, manyplies; *d*, true digestive stomach; *e*, lower end of œsophagus, § 278.

Circulating Apparatus.

111. Interior of *Diplozoon paradoxum*; showing on one side, *a*, the digestive system; and, on the other, *b*, the circulating system, § 272, 298.
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FIG.

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120. Plan of Circulation in *Fishes*; *a*, systemic vein; *b*, auricle; *c* ventricle propelling venous blood to branchiæ; *d*, returning vessels uniting to constitute aorta, A, § 309.
121. Plan of Circulation in *Reptiles*; *a*, *a*, systemic veins, entering the right auricle, *b*; *d*, *d*, pulmonary veins, entering left auricle, *e*; *c*, common ventricle sending blood through A, the aorta, to the system, and through *f*, *f*, the pulmonary arteries to the lungs, § 310.
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139. Ditto more advanced, showing formation of digestive cavity, *a*; and of heart, *b*.

PLATE V.

Respiratory and Secreting Apparatus.

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FIG.
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148. Head of *Lamprey* showing the branchial openings, § 405.
149. Branchial arch of *Fish*, showing its separate filaments with blood-vessels at their base; A, transverse view of one pair, showing in section *c*, cartilaginous arch; *a*, branchial artery; *b*, branch returning arterialised blood to aorta, § 309, 405.
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153. Section of Skin showing exhalant apparatus; *a*, layers of epidermis; *b*, substance of dermis (true skin) *c*, sudoriferous gland; *d, d*, spiral exhalant ducts, § 434.
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160. Section of ditto.
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171. Section of lobule of human liver; *a*, branch of hepatic duct, between the subdivisions of which the vena porta ramifies; *b, b*, origins of hepatic vein, § 461.
172. Plans of origin of glands; A, B, C, progressive stages of evolution of gland connected with *a, b*, the alimentary canal, § 472.
173. Parotid gland in embryo *Sheep*.
174. *Cicatricula* or germ-spot in Bird's egg, § 320, 535.
175. Primitive trace appearing soon after commencement of incubation, § 535.
176. Plan of development of *Allantois* in embryo of Bird, at advanced stage of incubation; *a, a*, general envelope or chorion; *b, b*, germinal membrane; *c, c*, body of embryo; *d*, allantois with vessels distributed on it, § 539.

PLATE VI.

N.B. In the following sketches of the *Nervous System* in different classes of Animals, the continuous white lines represent nervous trunks, and the white or shaded spots indicate ganglia. Where these are surrounded by a dotted line, this expresses the general form of the Animals; and a *small* dotted circle, where it occurs, points out the position of the œsophagus or entrance to the digestive cavity.

177. Nervous system of *Actinia* (Sea-Anemone), § 564.
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183. ——————— *Nautilus* (testaceous Cephalopode), § 569.
184. ——————— *Sepia* (naked Cephalopode).
185. ——————— *Strongylus* (parasitic worm), § 571.

FIG.
186. Nervous system of *Earthworm* (Annelide).
187. ————————— *Hydatina* (Wheel-animalcule).
188. ————————— *Barnacle* (Cirrhopode).
189. ————————— *Aphrodita* (Annelide).
190. ————————— *Scolopendra* (Myriapode).
191. ————————— Larva of *Sphinx ligustri* (Insect); A, Cephalic ganglia, § 572.
192. ————————— Ditto at period of first change; A, portion of thoracic cord, showing respiratory nerves; B, viewof ganglion from above; C, lateral view of do., § 570,3.
193. Nervous system of Pupa of *Sphinx ligustri* (privet-hawk-moth), § 573.
194. ————————— Imago of *Sphinx ligustri*, § 574.
195. ————————— *Melolontha* (Cockchaffer), § 575.
196. ————————— *Ranatra linearis* (Hemipterous Insect).
197. ————————— *Talitrus locusta* (Sand-hopper, Isopod Crustaceous animal), § 576.
198. ————————— *Maia squamado* (Crab).
199. ————————— Spider.

In the following figures, the letter *a*, points to the olfactory ganglia; *b*, to the cerebral hemispheres or ganglia; *c*, to the optic lobes or ganglia; *d*, to the cerebellum; and *e*, to the spinal cord.

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202. ——— *Raia rubus* (Ray).
203. ——— Grey Lizard, § 581.
204. ——— Frog.
205. ——— *Testudo mydas*, (Green Turtle).
206-9. Development of Nervous system in Chick, § 583.
210. Brain of Cassowary, § 581.
211. ——— Lion, § 582.
212. Origins of nerves from spinal cord, § 578.
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214. Brain of embryo at nine weeks.
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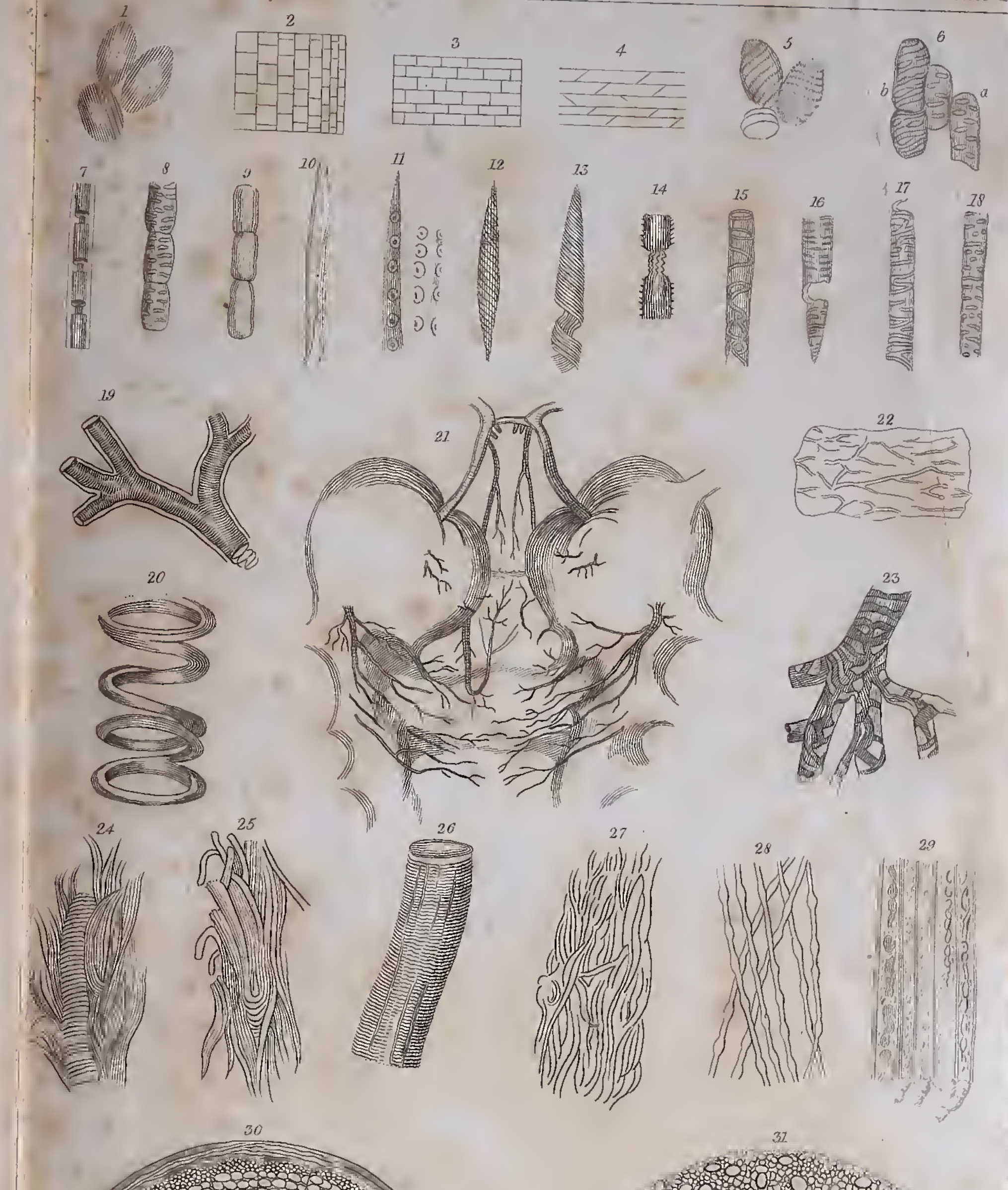
216. ————————— fifteen weeks.
217. ————————— twenty-seven weeks.
218-9. Brain and spinal cord of Tadpole, § 581.

CORRIGENDA.

Page 13, line 28, for "Eutozoa" read "Entozoa."
42, line 3 from bottom, for "Fig. 428," read "Fig. 28."
43, line 15, for "Chap. xv." read "Chap. xvi."
60, line 10 from bottom, for "Fig. 57" read "Fig. 59."
96, line 13, for "*Vermetus* (Fig. 82), and *Magilus*", read "*Vermetus* and *Magilus* (Fig. 82)."
141, running title, for "Physiology" read "Actions."
144, running title, for "Observations" read "Physiology."
341, line 10 from bottom, for "electrolytic" read "catalytic."



A. Carpenter del. V. Radlon sculp

Plate 2.

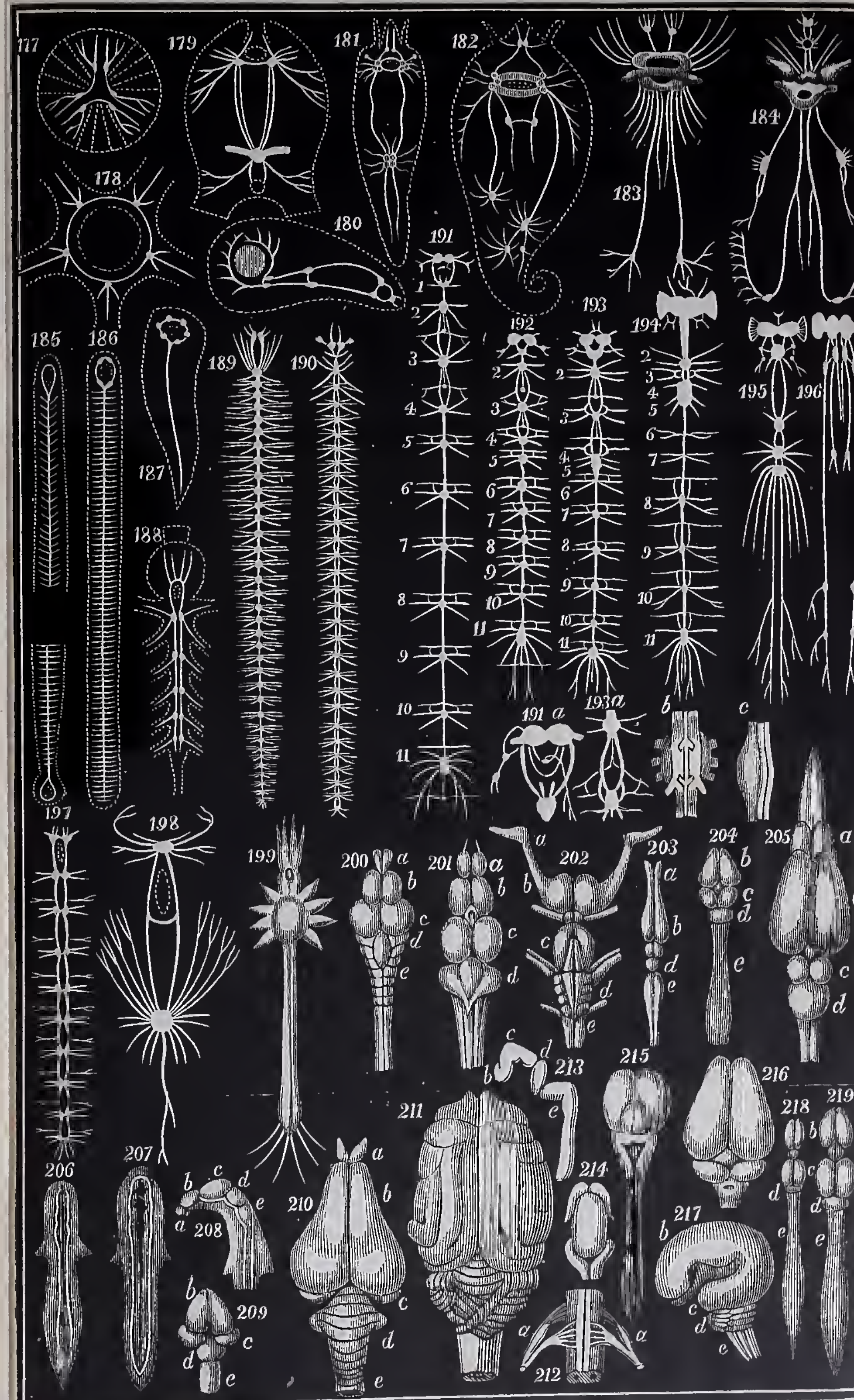
A. Carpenter, del. S. J. Lander, sculp.

W.B Carpenter, del.

S.J. Lunder, sc.

A. Carpenter, del.

J. Lander, sculp.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